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# 271 980

**U. S. A R M Y**  
**TRANSPORTATION RESEARCH COMMAND**  
**FORT EUSTIS, VIRGINIA**

TCREC Technical Report 62-8

**ANALYSIS OF AIR CUSHION VEHICLES**  
**ARMY LOGISTIC OVER THE SHORE (LOTS) OPERATION**

**VOLUME 1**

Task 9R99-01-005-07

Contract DA 44-177-TC-723

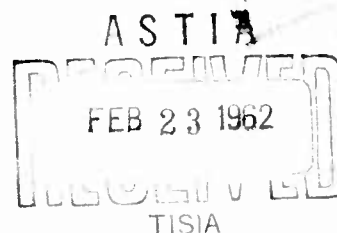
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Newport Beach, California

XEROX



The findings and recommendations contained in this report are those of the contractor and do not necessarily reflect the views of the Chief of Transportation or the Department of the Army.

## SPECIAL PROGRAMS OPERATIONS

Submitted to:

U. S. Army Transportation  
Research Command  
Fort Eustis, Virginia

CONTRACT NO. DA 44-177-TC-723

# TECHNICAL REPORT

ANALYSIS OF AIR CUSHION VEHICLES IN

## ARMY LOGISTIC OVER THE SHORE (LOTS) OPERATIONS

VOLUME 1. SUMMARY REPORT

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
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December 1961

# AERONUTRONIC

A DIVISION OF *Ford Motor Company.*

**FORD ROAD / NEWPORT BEACH, CALIFORNIA**

## SUMMARY

A critical examination of the LOTS mission has been accomplished to determine those operational and environmental factors that critically influence ACV lighterage design. Available technical theory and data are applied in determining practical ACV design characteristics for lighterage to be used within the limiting operational and environmental factors thus established.

A conclusion has been reached that the LOTS mission is unduly restricted by the utilization of low speed lighterage. The acquisition of high speed amphibious lighters within the Army inventory will greatly increase the distances to which LOTS lighterage operations can be extended economically within the 1965-1970 period. This extension of the practical operational radii of lighterage will greatly expand the patterns that can be developed for the dispersal of shipping as a means of passive defense against the threat of mass destruction weapons. It will add greatly to the flexibility and effectiveness of theater lighterage operations.

An ACV lighter designed to operate at a clearance height of 3 feet is considered capable of safely surmounting and negotiating the waves and surf generally associated with sea conditions in which ship unloading operations can be continued. The 3 foot operating height provides sufficient terrain clearance for a significant improvement in existing off-road mobility for the inland portion of the mission.

The overland mobility of ACV amphibious lighterage is unaffected by deteriorated route surface conditions that appreciably slow or completely halt the movement of ground contact vehicles.

A minimum cargo space of 11 feet by 35 feet is required in the 10 ton to 15 ton capacity lighters to provide sufficient space to load either a high percentage of the Army vehicles falling within these weight limitations, or to load to capacity with military dry cargo. These cargo compartment dimensions appear compatible with over-all vehicle design characteristics.

Limiting plan dimensions for loading the lighters on hatches of MSTs and commercial cargo ships generally constrain the vehicle size to 35 feet by 70 feet. Within this restraint, transshipment of a given cargo transfer productivity in ACV lighterage for use in the currently planned short radius LOTS mission poses no greater problem than does the transshipment of an equal productivity in wheeled amphibious lighters. At operating distances greater than those currently planned for the LOTS lighterage mission, which is considered to be highly desirable for the 1965-1970 time period, a greater productive capacity in ACV lighterage can be transhipped in an average grouping of MSTs and commercial cargo ships.

ACV lighterage, at this point in design development, are considered to offer an appreciable potential for self deployment over extended overwater distances on the order of 1,000 to 1,500 nautical miles.

Application of flexible skirts to the ACV design is highly effective in reducing the power requirements and produces an ACV amphibious lighter economically competitive with wheeled amphibians. The state of development of flexible skirt design and fabrication techniques has not progressed to the point where selective differentiation can be made between the full and partial skirt in the ACV amphibious lighter application. A 10 ton capacity partially skirted ACV lighter and a 15 ton capacity fully skirted ACV lighter are recommended for continuing analysis and further comparative evaluation in determining the most desirable configuration of an ACV lighter. Experimental development and tests of ACV flexible skirts, currently being conducted, give promise of furnishing the technical information of the operational practicalities and the optimum lengths of peripheral skirts to be used in ACV lighterage design.

ACV lighters are found to be economically competitive with wheeled amphibians at the operating radii of 3 miles overwater and 6 miles over land currently used as general planning factors for the LOTS lighterage mission. As operational radii are extended beyond these average distances, the ACV lighter shows a progressively increasing economic advantage over the wheeled amphibians.

Design, construction, and test of an ACV lighter in realistic LOTS operations appear justifiable and are recommended for an early date. Such tests will provide for the more precise definition of the design and operational factors which do not lend themselves to analyses and serve as a basis for refinement of the criteria developed herein.



## INTRODUCTION

An analysis of the application of air cushion vehicles (ACV) as amphibious lighters in the Army Logistics-Over-The-Shore (LOTS) mission has been accomplished. The detailed presentation of premises, technical analyses and results are presented in Volume II of this Report. Volume I presents herewith, a resume of the Technical Report with the major emphasis placed upon presentation of the results and conclusions. No references are made to the sources of the data quoted, nor are the premises for conclusions developed in detail. The Technical Report (Volume II) should be referred to for such detailed information.

The study was conducted under Contract DA-44-177-TC-723 for the U. S. Army Transportation Research Command (TRECOM). The study commenced on 15 March 1961 and was concluded with the issuance of the final report consisting of this Summary Report and the Technical Report.

Responsibility for conducting the study was assigned to the Air Cushion Vehicle Department of Aeronutronic Division of Ford Motor Company, Mr. M. F. Southcote, Manager. Mr. William E. Sickles of U. S. Army TRECOM served as the Army's technical representative and contracting officer's representative. Colonel A. M. Steinkrauss was the contracting officer for TRECOM.

## OBJECTIVES

Four fundamental objectives were pursued during the study:

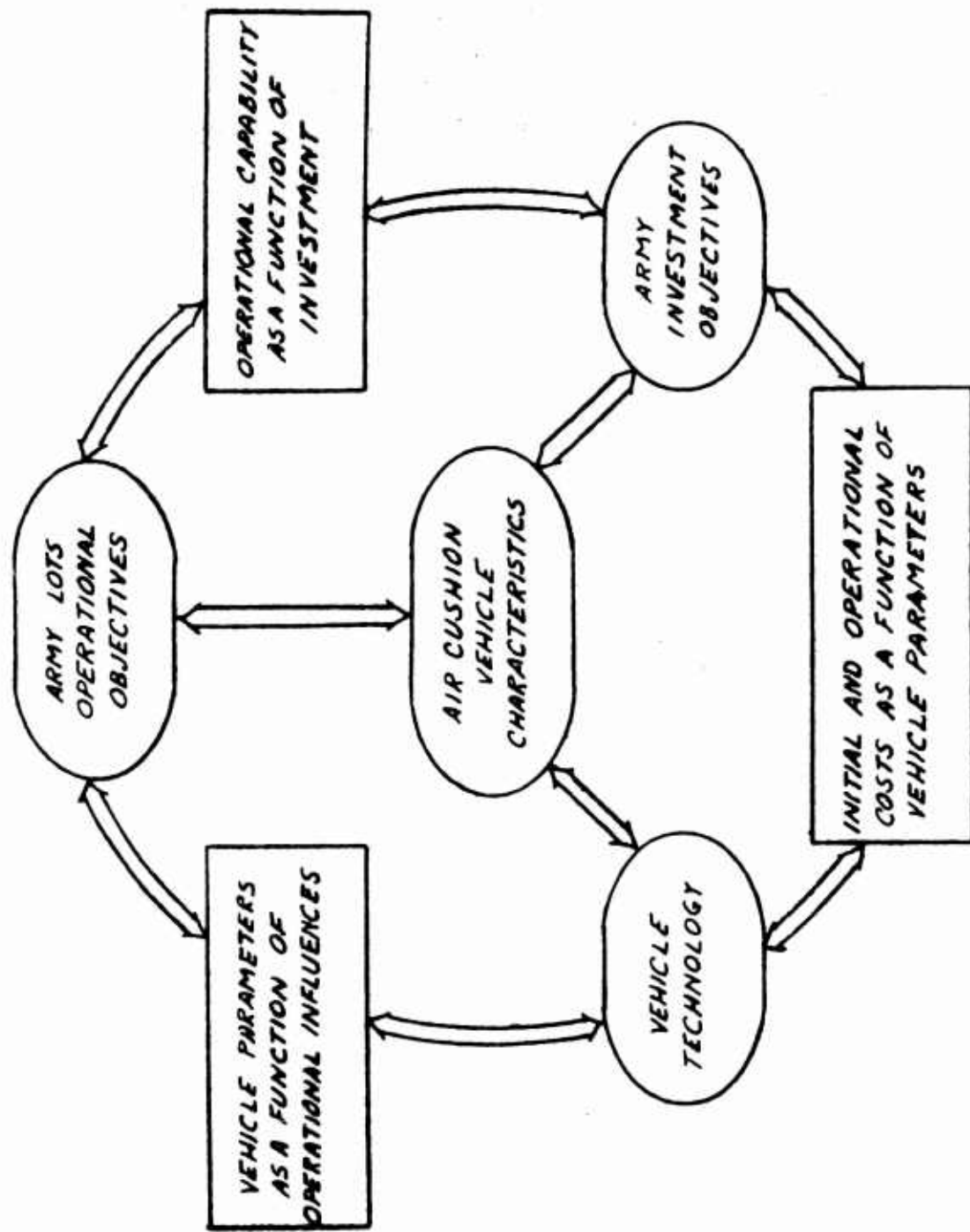
- A. A formulation of the operational criteria for an air cushion vehicle intended for use as a lighter in Army LOTS operations and preliminary estimates of air cushion vehicle design characteristics and configurations.
- B. A comparison of the LOTS system costs utilizing wheeled amphibious lighterage, helicopters as applicable, and air cushion vehicle lighters.
- C. A determination of whether the ACV is operationally and economically useful as LOTS lighterage and whether ACVs should be recommended to replace or complement current forms of lighterage.
- D. A determination of possible improvements in LOTS operational efficiency, capability and flexibility that may be possible with the introduction of air cushion vehicles.

The numerous factors involved in a study of this nature cannot be analyzed independently. The following study items are given only to provide an insight into the major factors considered and the accompanying figure of LOTS Operations Interactions indicates how they lead to the formulation of vehicle performance and design criteria.

- A. Army LOTS operational objectives
  - (1) Current and future LOTS operation concepts
  - (2) Mission timing and configuration
- B. Army investment objectives
  - (1) Flexibility and response to operation contingencies
  - (2) Economy of operation with maximum productivity in the LOTS missions
- C. Vehicle technology
  - (1) Estimated state-of-the-art performance
  - (2) Relative performance of various vehicle concepts

- D. Vehicle parameters as a function of operational influences
  - (1) Environment (land and water)
  - (2) Cargo handling and cargo characteristics
- E. Operational capability as a function of investment
  - (1) Operating costs
  - (2) Manpower requirements
  - (3) Fuel requirements
  - (4) Inventory costs
- F. Initial and operational costs as a function of vehicle performance parameters
  - (1) Payload
  - (2) Cargo space
  - (3) Speed
  - (4) Range
- G. Air cushion vehicle characteristics
  - (1) Design criteria
  - (2) Possible vehicle types
  - (3) Configuration variables

## LOTS OPERATION AND AIR CUSHION VEHICLE INTERACTIONS



## THE LOTS OPERATION

The advent of nuclear warfare brought an early realization that large military concentrations of men and material must be eliminated, except as required in direct contact with the enemy. The wide dispersal of forces, dictated by the requirements for passive nuclear defense, has increased the requirements for high speed mobility in bringing about the tactical concentrations need to overwhelm enemy centers of resistance. These requirements for dispersal and mobility of combat forces apply equally to combat support operations.

A concept of Logistics Over The Shore (LOTS) operations has been developed by the Army to satisfy the above requirement as it applies to the unloading of resupply shipping and lightering of resupply cargo. In this concept use of major ports is largely eliminated and, in lieu thereof, resupply cargo is unloaded from ships lying at dispersed anchorages off shore. The cargo is transported by amphibious lighter to the shore, over the beach and inland to widely dispersed cargo transfer and storage sites. That portion of the resupply cargo that is vehicular may be unloaded at or near the beach by roll off discharge for immediate dispersal under its own power.

General planning factors for the LOTS lighterage mission are used to develop force requirements and organizational structure of lighterage organizations. These planning factors, as currently used, are based upon the daily resupply requirements of a theater division slice and apply to a ship unloading site satisfying these resupply requirements. The planning factors constrain amphibious lighterage operations to an average of 3 miles off shore and an average of 6 miles inland. They are considered to be restricted to these values primarily because of the rapid degradation in the productivity of low speed lighterage as operating radii are extended.

Speed increases the responsiveness of lighterage to the changing military situation and acts to extend the distances over which it becomes economical to conduct lighterage operations. The combination of extended operating

distances and timely response to operating requirements offer the following military advantages:

- (1) Affords responsible commanders greater latitude in choice of ship unloading sites and added diversity in ship dispersal patterns.
- (2) Affords a similar increase in flexibility in the dispersal of inland cargo transfer and unloading sites.
- (3) Permits rapid concentration of lighterage from diverse locations for maximum rate unloading at a single site or to meet the demands of local variations in work loads.
- (4) Provides rapid response to a lighter command and control system with reduction in the queuing problem and increased flexibility in adjustment to changes within localized operations.
- (5) Makes selective discharge of priority LOTS cargo with intersite distribution by lighter an economically attainable objective.
- (6) Permits self deployment of lighterage (within range limitations) at speeds in excess of the rate of advance of fast amphibious shipping.

The attractiveness of these military capabilities are considered sufficiently important to warrant analysis of lighterage operations within parameters representing advances in amphibious lighter performance and possible extensions of the current LOTS concept. General LOTS planning factors in use today with those that are believed practical of attainment in the 1965-1970 period through the use of improved cargo handling techniques and high speed amphibious lighterage are set forth in the following table.

LOTS OPERATION PLANNING FACTORS  
ARMY THEATER DIVISION SLICE

PLANNING FACTOR	CURRENT VALUES	VALUES FOR 1965 to 1970
Ship unloading sites	1	1
Ships served per site	2	1
Ship hatches worked per site (5 per ship)	10	5
Dry cargo transferred per site	1440 s tons/day	1440 s tons/day
Working day	20 hours	20 hours
Ship hatch rate	7.2 s.tons/hr.	15 s.tons/hr.
Lighter unloading rate	14.4 s.tons/hr.	20 s.tons/hr.
Overwater mission radius	3 s. miles	5 to 75 n. miles
Overland mission radius	6 s. miles	5 to 10 n. miles

### MILITARY CARGO CHARACTERISTICS

It is estimated that of the 1,440 short tons of dry cargo comprising the daily resupply requirements of an Army Theater Division Slice, 34 percent will be containerized in standard Conex containers, 16 percent will be palletized on standard pallets, 25 percent will be bulk and filler cargo, and 25 percent will be vehicle replacements. Therefore, lighterage designed to satisfy the basic economic and operational objectives of the LOTS operation must have acceptable productivity in transporting the above distribution of cargo. It should have acceptable productivity in other theater lighterage missions such as the general unloading of combat and combat support organizations that may be brought into the theater after the initiation of the LOTS operation. As such organizations are highly mobile, the greater percentage of the cargo they represent will be vehicular. Accordingly, an analysis of lighterage capability in transporting the containerized, palletized and vehicular cargo was undertaken. For the purpose of the analysis, bulk and filler cargo was assumed to fall within the space and weight limitations of containerized cargo.

The analysis of the current family of wheeled amphibious lighters reveals that those in the low and intermediate payload capacities are seriously limited in cargo space for the transport of the significant and growing proportion of vehicles included in military cargo. The intermediate and heavy payload wheeled amphibians are similarly restricted in their ability to transport a capacity load of single tiered containerized and palletized cargo. The analysis was carried further to determine the cargo space dimensions required to carry capacity loads of single tiered palletized cargo, large size Conex containers, and the major proportion of military vehicles falling within selected weight classifications. The spread of vehicles by weight classification, number and planform dimension encountered in the ROTAD and ROCAD organizations was found to define the distribution of vehicles in Army combat and combat support organizations and is used accordingly.



The results of the above investigations are summarized in the following table of Amphibious Lighterage and Cargo. From these results, it is concluded that, if a family of ACV lighters is not being considered, an ACV amphibious lighter of from 10 to 15 tons capacity, incorporating cargo space dimensions approximating those indicated, would be a highly productive LOTS carrier in the 1965-1970 period. It would have acceptable utility in the lighterage operations associated with general unloading of the theater build up of combat and combat support organizations. It is further concluded that little productivity is gained by increasing lighter capacity above 15 tons until a capability of carrying the heaviest of Army equipments is realized.

AMPHIBIOUS LIGHTERAGE & CARGO  
DIMENSIONAL COMPATIBILITY OF MILITARY CARGO AND LIGHTER CARGO SPACE

LIGHTER CAPACITY (SHORT TONS)	LIGHTER CARGO SPACE DIMENSIONS (FEET)	LARGE SIZE		PALLETS (1 TON)		CARRYING CAPABILITY IN		
		CONEX CONTAINERS	SPACE LIMITED LOAD	SPACE LIMITED LOAD	SPACE LIMITED LOAD	ORGANIZATIONAL VEHICLES		
		(SHORT TONS)	(SHORT TONS)	(SHORT TONS)	(SHORT TONS)	% OF TOTAL VEHICLES ROTAD	% OF TOTAL VEHICLES ROCAD	% OF TOTAL VEHICLES WFS ROTAD
5	9 x 25	None	None	None	None	88.5	55.6	37.5
10	9 x 30	None	None	None	None	95.5	70.0	59.5
15	11 x 35	None	None	14	14	96.0	76.5	62.1
25	13 x 39	15-25	18	18	18	96.7	90.5	86.0
60 (BARC)	14 x 38.5	24-40	26	26	26	100	100	100

## WATER OPERATION CRITERIA

The most adverse sea environment in which maximum rate ship-to-lighter transfer of cargo can be accomplished, defines the sea conditions in which the ACV designed for LOTS operations must operate at rated performance. The ocean wave heights at which the maximum calm sea off-loading rate begins to deteriorate is estimated to be at significant wave heights on the order of 3.5 feet. This is characteristic of a Sea State of 3.

An ACV designed for no wave impact would have to be capable of operating heights in excess of 5 feet in this sea condition to assure a high probability of no wave impact (one impact in one million trips) as indicated on the figure of Wave Probabilities on Trip Basis. A LOTS ACV, for many reasons, would be designed for flotation and water impact. Partial or complete power failure, the possibility of impacting isolated waves higher than the vehicle base under less than ideal daylight and night visibility conditions, and loads imposed by wave action and contact with the side of the cargo ship when transferring cargo, may well result in a structural design sufficient to withstand wave impact.

Considering crew comfort and vehicle dynamics it is estimated that one wave impact every 30 to 90 seconds is tolerable. For conservatism a criterion of one wave impact every 90 seconds has been selected which corresponds to impact with one out of every one-hundred waves in a Sea State 3. This requires an operating height on the order of 3.0 feet, as shown on the figure of Wave Probabilities on a Frequency Basis.

Data collected on a world-wide basis are shown on the figure of Ocean Wave Height Frequencies and indicate that Sea States of 3 or less can be expected 60 percent of the time. In favorable locations and seasons, sea conditions more favorable than a Sea State 3 can be expected almost 90 percent of the time and will permit operation of the ACV at reduced heights with greater than rated payloads.

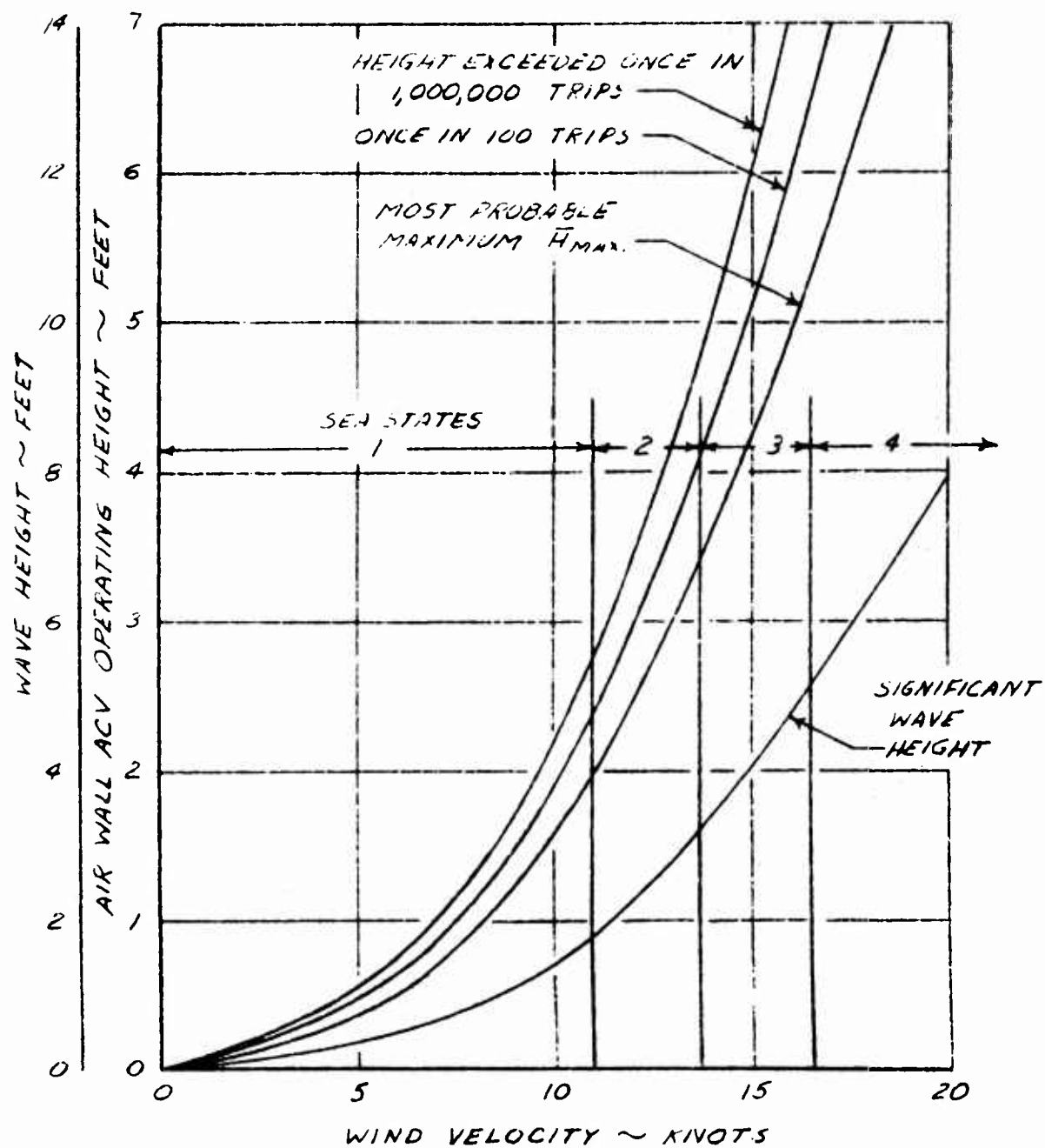
Wave impact design is expected to be dictated by the practical considerations mentioned above and such design results in a substantial reduction in the required operating height, therefore, this has been selected as a design criterion. The Sea State of 3 or less is experienced the majority of the time and is the sea condition at which effective ship unloading begins to degrade. Therefore, the 3.0 foot operating height required for wave impact operation in such a sea has been selected as the design operating height.

# WAVE HEIGHT PROBABILITIES

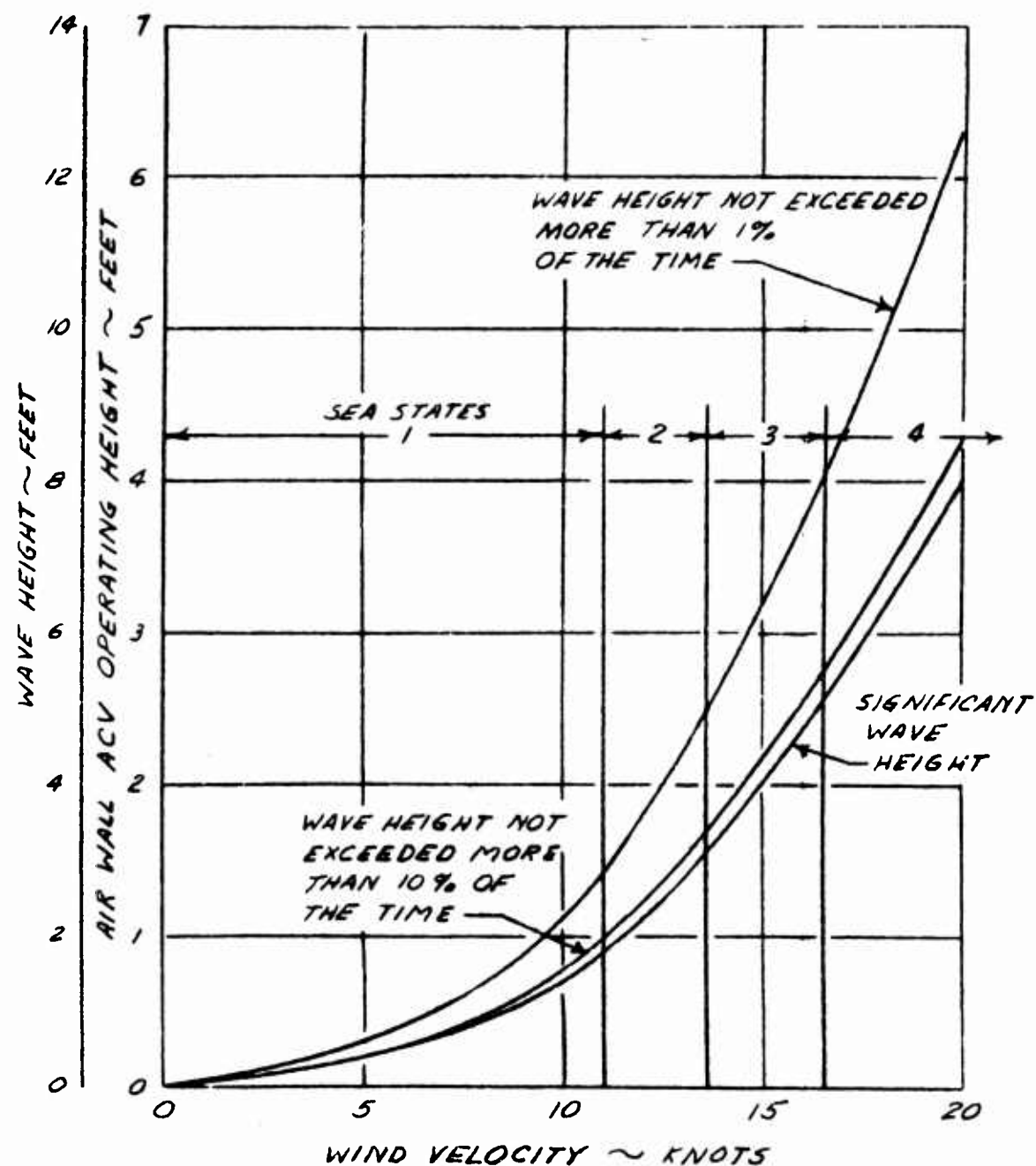
## TRIP BASIS

TRIP TIME 3.3 HOURS

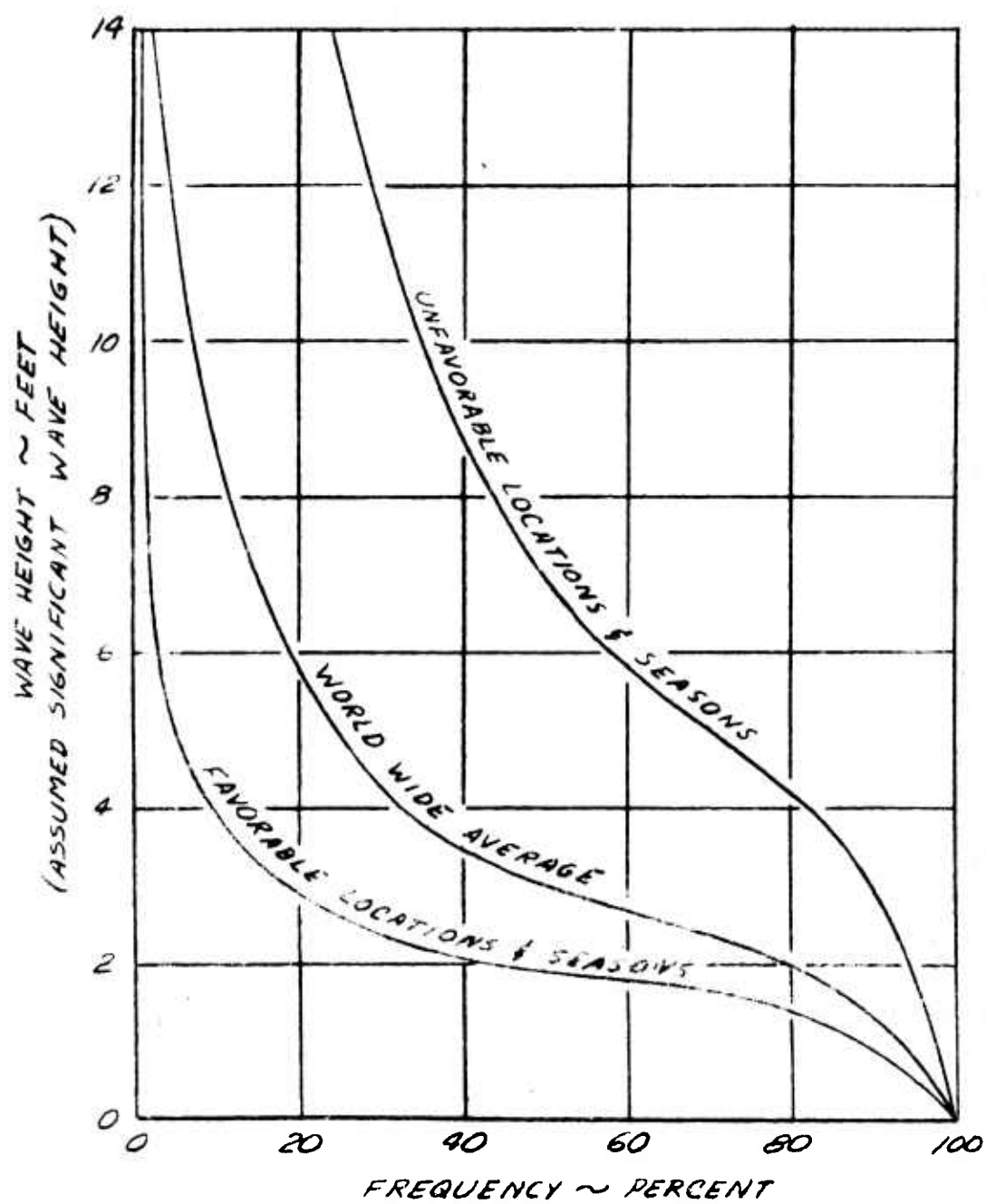
VEHICLE SPEED 40 KNOTS



# WAVE HEIGHT PROBABILITIES FREQUENCY OF ENCOUNTER



# BAND OF OCEAN WAVE HEIGHT FREQUENCIES



## OVERLAND OPERATION

Defining terrain in quantified form to permit specification of the vehicle characteristics required for cross-country operation is an almost impossible task, since it requires a detailed survey of the earth's surface. Land vehicle mobility is generally specified by vehicle characteristics or capabilities, such as clearance height, angle of break, gradability, ground pressure, etc. Historically, the improvements in true cross-country mobility of ground contact vehicles have been accomplished in a step-wise fashion. Improvements in technology and mechanization have resulted in gradual advances in vehicle mobility over unprepared terrain. A meaningful and specific method of developing the cross-country performance objectives for an air cushion vehicle is to examine the currently desired performance improvements in conventional land transport vehicles and utilize these as minimum criteria for an air cushion vehicle.

Minimum criteria for the next generation of cross-country transport vehicles, as proposed by the Transportation Corps, are shown in the table of Minimum Overland Mobility Characteristics. These criteria for improved transport vehicles were determined with wheeled or tracked vehicles in mind. However, they do represent what is considered by the Transportation Corps as an acceptable advancement in the mobility of what may be termed "surface transportation vehicles".

An air cushion vehicle design would have no difficulty in attaining any of these criteria with the possible exception of gradability. The gradability requirement is indicative of the capability of wheeled and tracked vehicles only when the soil conditions are excellent for ground traction. Air cushion vehicles can be designed to meet the 60% grade



requirement with some economic penalty. However, the air cushion vehicle capability for operating over any adverse soil condition, with no degradation in its performance, is indicative of its ability to circumnavigate the steepest grades which are often forced upon the conventional ground contact vehicles.

Air cushion vehicles have inherent capabilities not obtainable with the conventional ground contact vehicles. The ability to traverse any terrain profile that does not present obstacles and slopes beyond the capability of the air cushion vehicle with absolutely no performance degradation because of soil type or condition (mud, marsh, sand, snow, ice, water, etc.) is, in itself, a capability that no vehicle other than truly air borne vehicles have. The advantage of such a capability in a military situation is immeasurable. Even if the terrain mobility capabilities of wheeled or tracked vehicles over good soil conditions are just matched by an air cushion vehicle, its adverse soil capabilities should prove to make its existence in the military inventory worthwhile.

The overload mobility of air cushion vehicles offers the following advantages over ground traction vehicles:

- (1) No performance degradation due to adverse soil conditions.
- (2) Ability to utilize as routes certain terrain features not useable by all ground traction vehicles (mud flats, marches, swamps, ice, water, sand, etc.).
- (3) More ability to circumnavigate obstacles.

Thus it is believed that an air cushion vehicle with somewhat less hard soil **slope** capability than future ground traction vehicles would actually have more over-all mobility.

# MINIMUM OVERLAND MOBILITY CHARACTERISTICS

Normal Operating Height	At least 26 inches
Ground Pressure	Less than 1.9 PSI
Land Cruise Speed	At least 35 knots (on road)
Gradability	60 percent on hard ground
Turning Radius	23 feet on pivot
Cruising Range	300 nautical miles
Fordability	Floatable
Buoyancy	Buoyant
Minimum Freeboard	13 inches
Waterspeed	At least 7 knots

## AIR CUSHION VEHICLE ANALYSIS

Air cushion vehicles employing the peripheral jet (air wall), the partially skirted air wall, the fully skirted and the amphibious (retractable skeg) hydroskimmer concepts were studied for possible application to LOTS operations. Due to the amphibious nature of LOTS operations and the requirement for efficient inland operation at low speeds; the ram-wing and simple hydroskimmer types were not considered. Additionally, the relatively inferior performance of unskirted plenum chamber type vehicles eliminates them from consideration. Vehicles employing lifting flow recirculation concepts were not included since the engineering state-of-the-art made their use questionable.

A computer program was especially developed to determine the air cushion vehicle characteristics which resulted in the necessary productivity at minimum daily lighterage cost and to determine the sensitivity of the results to the assumptions used. The selection of air cushion vehicles was based on their ability to provide minimum lighterage costs in LOTS operations.

Assumed structure weights and costs and estimated propulsion system weights, costs and efficiencies were employed in determining the air cushion vehicle characteristics.. The assumptions are briefly summarized in the table of Air Cushion Vehicle Assumptions and Estimates, which also presents the range of parameter values that were investigated.

Results of the investigation are summarized on the figure of The Comparison of Minimum Cost Air Cushion Lighterage Vehicles. Data given are for vehicles designed to operate in seas characterized by 3.5 foot significant wave heights with impact of no more than one

out of a hundred waves; and to provide three foot obstacle clearance on land. The nominal assumptions of costs and weights are implicit in the data shown. The ACVs are required to have sufficient fuel on board for an inland radius of 5 nautical miles at 15 knots; for a delay time of 16 minutes per cycle at cruise power; and the fuel necessary to operate at ten percent of cruise power while loading at shipside in addition to operating at rated cruise speeds for the overwater radius.

The air wall vehicle has the poorest economies at all mission radii investigated. The partially skirted air wall vehicle with a 10 ton payload and 80 knot cruise, the fully skirted vehicle with a 15 ton payload and 40 knot cruise, all have virtually the same lighterage economy at a 25 nautical mile water radius.

The hydroskimmer vehicle is not considered attractive for the lighterage missions since its economies are not superior to the other vehicles and the mechanical complexities of skeg retraction detract from its use.

The fully skirted and the partially skirted vehicles are economically competitive. The fully skirted vehicle is somewhat superior at overwater radii less than 25 nautical miles. The partially skirted vehicle is superior at overwater radii exceeding 25 nautical miles.

The partially skirted 10 ton payload ACV and the fully skirted 15 ton payload ACV were selected for further comparison with full recognition that the final ACV lighter for LOTS operations may prove to be an amalgamation of characteristics provided by both. The operational capabilities and design characteristics of these vehicles do, however, typify what is believed achievable with air cushion vehicles in LOTS operations of the 1965 to 1970 time period. The primary characteristics of these vehicles, as determined by the analysis procedures, are presented in the table of Selected Air Cushion Vehicle Characteristics.

Sensitivity analyses indicated that the assumed structure and propulsion system weights were the most influential assumptions affecting the ACV performance and economy. The specification of maneuver capabilities greater than .15 'g' result in installed power plant sizes larger than required by cruise and hover operation. Importantly, the analysis showed that vehicle characteristics were not sensitive to individual assumed costing parameters and the vehicle size was unchanged by variations in structure weight assumptions.

Sensitivity analyses of the air cushion vehicle show that changes to individual assumed costing parameters by as much as 50 percent result in only nominal changes to vehicle physical characteristics for minimum cost lighterage. These variations do not materially affect the relative economic standing of the vehicle types. The analytic procedures used herein to determine characteristics of minimum cost ACVs can therefore be utilized with a high degree of confidence that differences between an initially assumed cost parameter and its actual value will not change the vehicle configuration significantly. However, if several cost parameters are simultaneously assumed either too conservatively or too optimistically, then significant changes to both cost and vehicle configuration can occur.

The sensitivity analyses of air cushion vehicles also show that vehicle costs are especially sensitive to assumptions of specific structure weight and specific propulsion system weight. A 10 percent change in structure or propulsion weights can increase operating costs approximately 5 percent. The assumed structure specific weight is the least certain of the two. However, vehicle size is not sensitive to assumed weight variations approximating 50 percent. Additional effort in the form of vehicle tests and design studies are necessary and should be accomplished to more precisely define the structural weights of air cushion vehicles.

# SUMMARY OF AIR CUSHION VEHICLE ASSUMPTIONS AND ESTIMATES

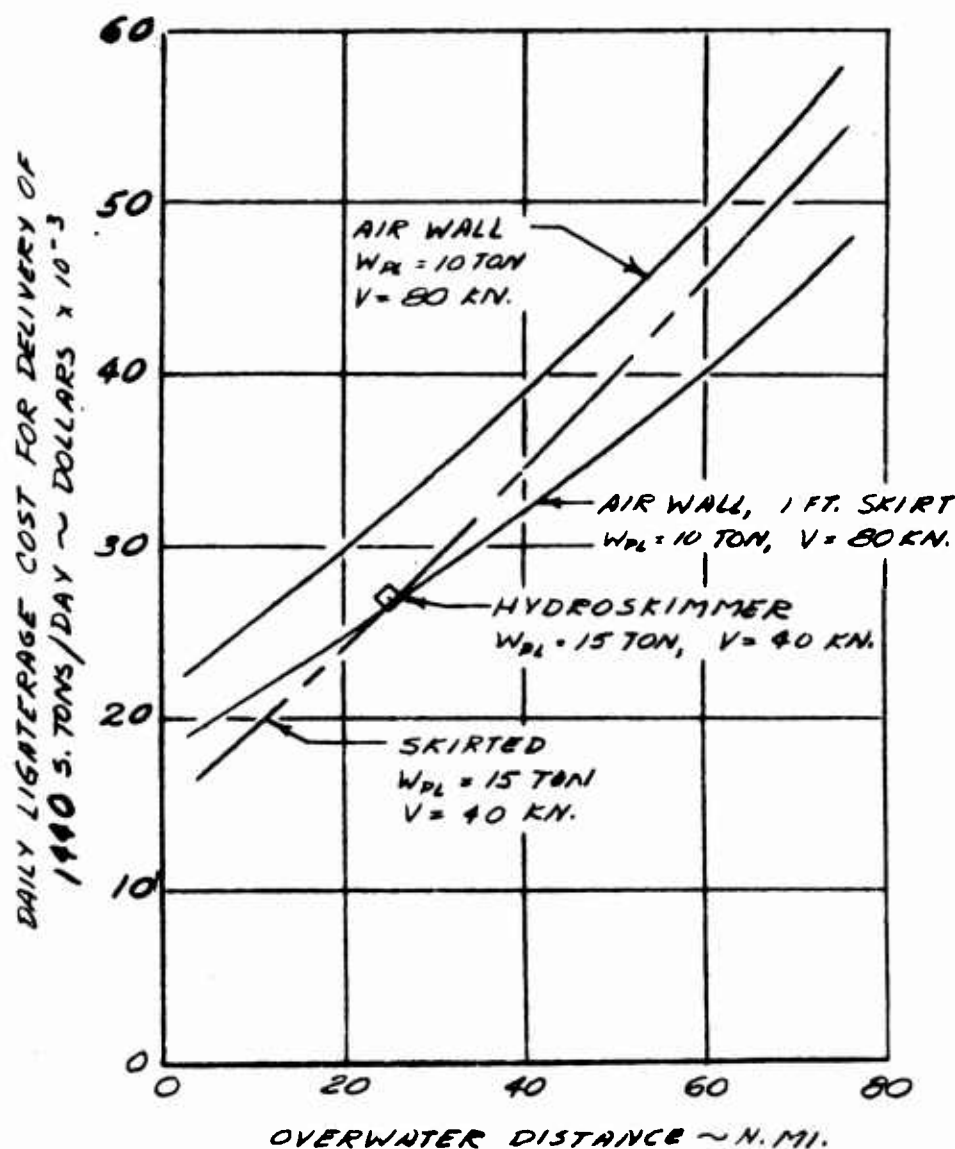
ITEM	NOMINAL VALUE	VARIATIONS
Overland Distance	5 N. Miles	0 to 10 N. Miles
Overwater Distance	25 N. Miles	5 to 75 N. Miles
Overland Speed	15 Knots	0 to 35 Knots
Overwater Speed	-	0 to 80 Knots
Payload	-	5 to 25 Tons
Operating Height	3.0 Ft.	.75 Ft. to 5.5 Ft.
Size Constraint	35 Ft. x 70 Ft.	19 Ft. x 35 Ft. & 24 Ft. x 60 Ft.
Planform Loading	-	10 lb/ft <sup>2</sup> to 100 lb/ft <sup>2</sup>
Maneuver Capability	.25 'g'	.1 'g' to .5 'g'
Weights		
Propulsion System	1.4 lb/SHP	1.4 & 2.0 lb/SHP
Structures - per unit planform area	2 + .67 $\sqrt{\frac{L^*}{S}}$	+ 50%
Costs		
Propulsion System	\$43/lb	\$36/lb to \$50/lb
Structure	\$6/lb	\$6/lb & \$15/lb
Propulsion Efficiency	-	50 & 75%
Lift Fan Efficiency	85%	-
Duct Efficiency	80%	-

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$\frac{*L}{S}$  equals planform loading

# COMPARISON OF MINIMUM COST AIR CUSHION LIGHTERAGE VEHICLES

$\lambda = 3.0$  FT., HATCH RATE = 15 TONS/HR.,  
LAND DISTANCE = 5 N. MI., LAND  
SPEED = 15 KN, .25'g' MANEUVER  
CAPABILITY, MAX. WIDTH = 35 FEET,  
DELAY TIME = .27 HR./CYCLE



# SELECTED AIR CUSHION VEHICLE CHARACTERISTICS

ITEM	FULLY SKIRTED 15 TON PAYLOAD	PARTIALLY SKIRTED 10 TON PAYLOAD
Gross Weight	46,000 LB	37,500 LB
Planform Loading	55.5 LB/FT <sup>2</sup>	19.6 LB/FT <sup>2</sup>
Width	20.5 FT	31.5 FT
Length	41.0 FT	63.0 FT (Stowed) 75.0 FT (Operating)
Base Area	831 FT <sup>2</sup>	1,907 FT <sup>2</sup>
Installed Power	3,400 SHP	3,160 SHP
Weight Empty	13,000 LB	15,300 LB
Max. Cruise Power	2,800 SHP	2,270 SHP
Cruise Fuel Consumption	2,015 LB/HR	1,645 LB/HR
Operating Height	3.0 FT	3.0 FT
Design Maneuver	.25 'g'	.25 'g'
Design Grade	25%	25%
Design Speed	40 KNOTS	80 KNOTS



## ACV LIGHTERAGE DESIGN CONSIDERATIONS

The following design considerations are tentatively established as basic requirements for full realization of the potential of ACV lighterage in LOTS operations. The existing air cushion vehicle technology and the lack of operational testing and experience preclude an exactness of specification in many instances. Where criteria have been quantified, the values are predicted upon reasonable assumptions of those required to obtain safety of operation and a practical operational capability in a first generation vehicle. Provision of sufficient capability to permit a full range of operational testing is paramount. As design studies progress, areas will undoubtedly develop where additional research and experimental test can be productive in refining the following quantified design criteria.

This study recommends two general configurations of ACV lighterage for more detailed consideration. Both are skirted types; one is a partially skirted peripheral jet configuration while the second is a fully skirted type. The difference in length and application of the flexible skirt resulted in differences in optimum planform dimensions, load capacities, operating speed and installed power. Military advantages accruing from either configuration are believed sufficient to warrant further developmental effort although the optimum length of skirt to be used in the ACV lighterage application is not precisely definable in view of the limited technical information developed to date.

The flexible skirt is undergoing development and test by this contractor and shows promise of early solution of the technical design and fabrication problems involved. However, this development has not progressed to the point where the question of the partial versus the full skirted application can be fully assessed. Accordingly, a specific configuration has not been selected. The following design criteria are believed fully applicable to ACV lighterage in the 10 to 15 tons load capacity classification. The criteria set forth

are believed of sufficient importance that they must be considered in developing a basic ACV lighterage layout and structural design.

#### PERFORMANCE CAPABILITIES

##### 1. OPERATING HEIGHT

An operating height of 3.0 feet is considered necessary for first generation skirted or partially skirted air cushion vehicles for use in LOTS operations.

##### 2. PAYLOAD

Design operating payload of from 10 to 15 short tons is required for transport of the major proportion of Army vehicular equipments and all dry cargoes.

##### 3. SPEED

Overwater operating speeds of from 40 to 80 knots are desirable for economy of ACV lighterage in LOTS operations. The degree of skirting provided the ACV will, to a large measure, dictate the overwater cruise speed. Efficient operation inland at speeds as low as 15 knots is also important to achieving economical ACV lighterage operations.

##### 4. MANEUVER

Lateral and longitudinal maneuver capability of .25 'g' during hover operation should be provided the first generation ACV lighter. Additionally, lateral maneuver capability of .25 'g' should be provided at the design cruise condition. Deceleration capabilities of .4 'g' to .5 'g' at forward cruise speed appear to be reasonable and readily available from provision of static longitudinal acceleration capabilities.

##### 5. GRADE CAPABILITY

"Holding" capability on a 25 percent grade, both longitudinally and laterally, will be obtained at design gross weight by provision of the recommended .25 'g' maneuver capability. Additional capability to approximately 35 percent grade at a steady state speed or 5 knots can be obtained by operating at reduced heights. Steeper than 35 percent grades can be negotiated for moderate distances by trading off forward speed.

#### OPERATIONALLY INDUCED CRITERIA

##### 1. CARGO SPACE

- a. Provide a minimum cargo space 11 feet wide by 35 feet long in the 10 to 15 ton capacity lighters.

Provide additional cargo space as practicable if overload operation at reduced operating height is contemplated. Provide a clear height in the cargo compartment of 11 feet.

- b. Provide for wheel and axle loading of the cargo compartment floor of 6,000 pounds and 13,000 pounds respectively.
- c. Provide for cargo compartment floor loading of 500 pounds per square foot.
- d. Provide structure against operationally induced vertical acceleration of 4 g.
- e. Provide for cargo tie down restraint of:
  - 4 g forward
  - 1 g vertical
  - 1 g lateral
  - 1 g rearward

Utilize aircraft tie down principles and gear as practical.

- f. Provide a replaceable buffer strip around the upper edge of the cargo compartment to protect against swaying cargo drafts being lowered into the lighter.
- g. Provide flooring structure to sustain vertical impact of 5 ton cargo drafts contacting the cargo compartment deck at a velocity of approximately 4 feet per second. If cargo positioning gear is installed in the lighter it may prove necessary only to provide a limited area of highly stressed cargo deck the width of the lighter cargo space and twelve feet in length. Dunnage of normal types may be considered as a partial cargo floor buffer.
- h. Provide full load capacity fuel tanks as a kit installation in the cargo compartment for the purpose of long range self deployment and to permit use of the lighter as a bulk fuel tanker.
- i. Provide an integral ramp or treadways for roll-off unloading of vehicular cargo operating under its own power. Provide for wheel and axle loading of 6,000 and 13,000 pounds, respectively and a ramp angle on level ground of not more than  $.15^{\circ}$ .

## 2. WAVE IMPACT

Provide structure sufficient to withstand wave impact when operating at normal cruising speed in a level attitude and with hard structure impinging at a level two feet below the wave crest.

### 3. BUOYANT OPERATION

- a. Provide compartmented buoyancy such that rupture of two adjacent compartments will not result in the loss of the lighter.
- b. Provide integral fenders for protection of the lighter structure from impact damage while coming alongside and loading at the ship's side in a State 3 Sea.
- c. Provide towing bitts and cleats for securing mooring lines.

### 4. GROUND HANDLING

- a. Provide ground handling gear with a static foot print pressure at designed gross weight of 15 pounds per square inch.
- b. Provide limited rolling mobility on hard surface for the purpose of "walking" the lighter away from a self unloaded cargo and for towed mobility in connection with maintenance operations.
- c. Provide base clearance when on ground handling gear of 24 inches above a flat surface.
- d. Provide jacking points capable of supporting the operating empty weight of the lighter.
- e. Provide sling hoisting points and a single point lifting sling for ship board loading and unloading.
- f. Provide for tow bar attachment fore and aft.

## PERSONNEL SAFETY REQUIREMENTS

### 1. SEAT BELTS

Provide safety belts at all crew members' stations. Shock mounted seats may be desirable for configurations employing forward positioned crew.

### 2. SEATS

Provide for removable bucket seats with seat belts for capacity passenger load.

### 3. WALKWAYS

Provide railed catwalks at the sides of the lighter cargo compartment to accommodate troops and stevedores loading aboard the lighter via cargo nets suspended over a ship's side. Provide appropriately located ladders for descent into the cargo compartment.

4. SAFETY GUARDS

Provide adequate guards or screens at fan and propeller inlets for personnel safety and as a guard against foreign object ingestion.

5. SAFETY IN MOORING

Provide safe areas for handling mooring lines when coming alongside a ship or in lieu thereof provide a remotely controlled automatic hook-up system.

6. HATCHES

Provide escape hatches from closed crew or passenger compartments.

ACV INDUCED ENVIRONMENTAL CRITERIA

1. SPRAY AND DUST

Provide spray and dust suppression to the extent required to permit adequate operator visibility. Note: peripheral skirting alleviates this problem.

2. INFRARED SIGNATURE

Provide insulation for engine hot section. Provide for engine exhaust into cushion air under the vehicle.

3. NOISE SUPPRESSION

Provide noise suppression to the extent necessary to insure crew comfort and passenger tolerance. Use of low tip speed fans (approximately 700 feet per second or less) is recommended.

4. VIBRATION SUPPRESSION

Provide a dynamically stable vehicle with machinery and aerodynamically induced accelerations held to less than 0.15 'g' in the frequency range of 0.2 to 5.0 cycles per second.

5. WAVE IMPACT ACCELERATIONS

Provide hull configuration to restrain wave impact accelerations to plus 4 'g' vertically and 4 'g' forward when striking the wave at not greater than two feet below its crest at rated operational cruising speed.

NAVIGATION AND COMMUNICATIONS

Provision of standard military navigation and communications equipment are implicit. Possible need is seen for radar navigation equipments and UHF-VHF

communications equipment. Provision of any special equipments should, however, be based on results of experimental vehicle tests in realistic LOTS operations.

#### MAINTENANCE PROVISIONS

Provisions for ease of maintenance applicable to other vehicles are also desirable for the ACV. For example the use of standard parts and components, interchangeability of components, ease of access through maintenance doors, etc., are equally germane to the ACV. The environment and characteristics of the ACV lighter do, however, suggest emphasis on the following points.

1. VEHICLE WASH DOWN

Provide for ease of wash down and removal of salt spray deposits.

2. SIMULTANEOUS MAINTENANCE

Provide for simultaneous maintenance of vehicle components. The size of the ACV and distribution of its propulsion components will probably permit inspection and maintenance to be accomplished efficiently in a shorter period of time by a larger maintenance crew than is possible with many other vehicles. Proper advantage should be taken of this factor to reduce maintenance down time by provision of adequate access to components and elimination of all possible sequential maintenance operations.

3. FUELING

Single point pressure fueling should be provided to permit maximum vehicle utilization and safety in refueling operations.

## AIR CUSHION VEHICLE CONFIGURATION

Design sketches of the two analytically determined vehicles were prepared in order to indicate their ability to accommodate desired cargo handling provisions and permit packaging of the necessary propulsion system components. No attempt was made to quantify vehicle weights or perform structural design analyses as these were beyond the program scope. Additionally, detail design studies to determine the most efficient cargo handling arrangements and cargo compartment space were not accomplished.

### Partially Skirted 10-Ton Payload Vehicle

Design Sketch A depicts the 10 ton payload partially skirted vehicle.

Notable features of this vehicle are:

- (1) The fold-away bow for ease of transshipment on MSTs vessels and for permitting lowering of the 15° slope vehicle roll-on, roll-off bow ramp.
- (2) Cargo compartment having minimum clear dimensions of 13 feet width, 60 feet length and 11 feet height. It is anticipated that no space limitation problems will be encountered in filling this vehicle's cargo compartment to an overload capacity (25 tons) when operating in environments permitting a 1.8 foot operating height.
- (3) Overhead traveling hoist for cargo positioning and for self cargo discharge to the ground or to trucks, when aft door rail extensions are opened.
- (4) Stevedoring and other personnel safety provisions in the form of combined turning vane and safety grills on the lifting fans, combined stator blade and safety grills on the shrouded propulsion fans, and side railings. Additionally, opened hatch doors provide stevedoring personnel walkways and flush cargo compartment ladders permit entry to and exit from the cargo compartment.

- (5) Four pairs of large tired wheels provide direct ground support in soft soils (15 psi) and permit towing of the vehicle during maintenance.
- (6) Shrouded propulsion and lateral acceleration fans permit 14° roll with respect to the cargo ship and 15° roll with respect to a boom lowered cargo draft. These roll angle allowances are considered adequate for compensating ship-lighter relative motion during shipside loading operations. Additionally, clear area between the fans combined with the integral traveling hoist permit most cargoes to be loaded between the longitudinally displaced propulsion-acceleration fans with little danger of fan damage.
- (7) Large inflatable bumpers permit lighter-to-ship contact during shipside cargo handling with minimum loads imposed on vehicle structure.
- (8) Simple spray deflectors are incorporated on the vehicle to minimize water spray.

#### Fully Skirted 15 Ton payload Vehicle

Design Sketch B depicts the fully skirted vehicle. The smaller size of this vehicle, in spite of its 50 percent greater payload, is apparent.

The cargo handling, environmental and personnel safety provisions shown for the fully skirted vehicle are similar to those enumerated for the partially skirted vehicle.

To depict an alternate internal cargo handling method the fully skirted vehicle is shown with a powered continuous conveyor belt spanning the width of the cargo compartment. Rapid cargo positioning and self unloading are, therefore, maintained on the fully skirted vehicle.

To provide adequate cargo clear-space within the smaller size of this vehicle it is desirable to split the propulsive and maneuvering thrust



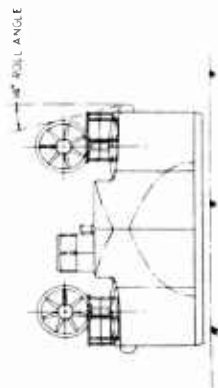
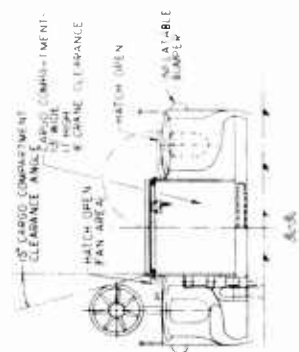
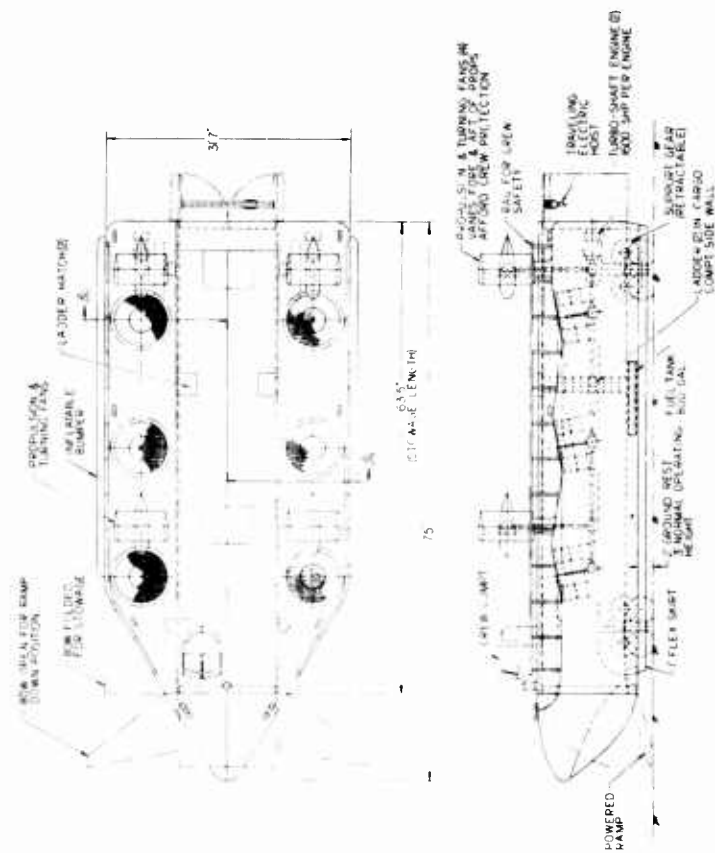
capabilities such that approximately one-half the maneuver propulsive force is integrated with the lift system, and the other half is obtained from the external aft-mounted shrouded and swiveling fans. The fans swivel 90° during shipside loading to provide for clearance with the ship and cargo compartment.

The cargo compartment of the fully skirted vehicle is 11 feet in width and 35 feet in length--adequate to handle practically all vehicular equipments with its payload capacity. No cargo compartment cover is provided the fully skirted vehicle because of its lower (40 knot) design speed. The 40 knot cruise speed is considered low enough to impose no more than negligible aerodynamic drag penalties. The low lifting air flow volume of the skirted vehicle and its relatively low 40 knot cruise speed minimize wind driven water spray and dust problems.

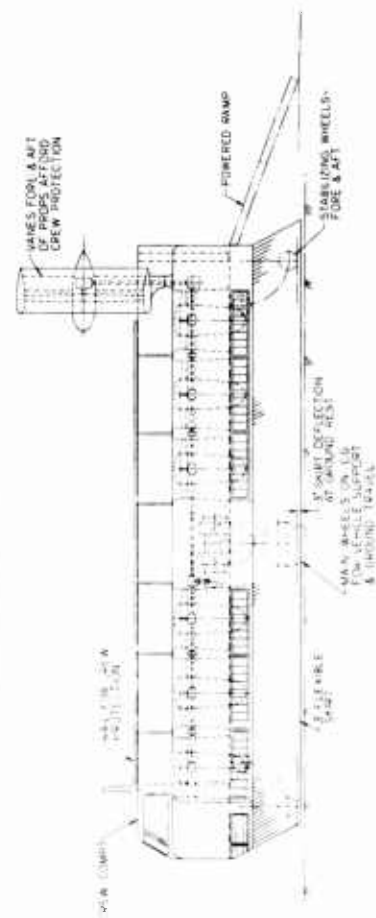
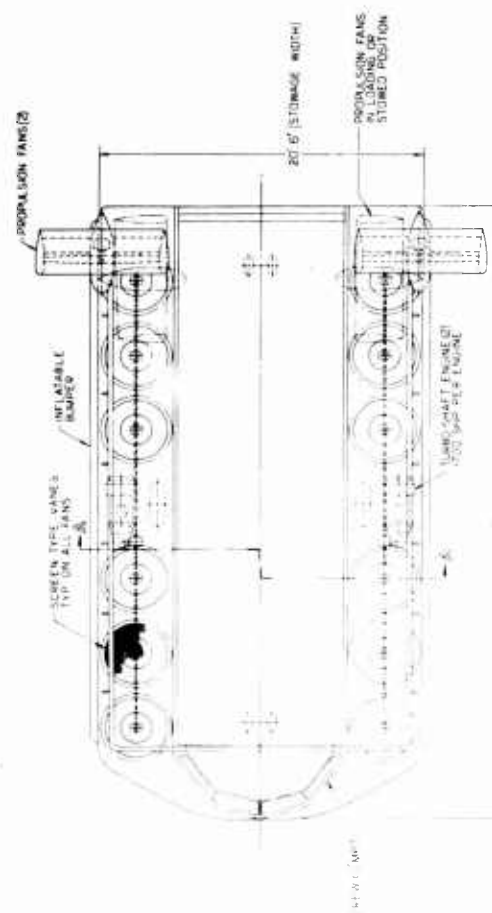
The considerations of vehicle signature-from-noise and basic propulsive system efficiency lead to selection of multiple small diameter fans for both vehicles. Such fans, coupled with continuously contracting duct area, permit good distribution of lifting air flow volume and relatively low fan tip speeds (500 to 600 feet per second) serve to minimize fan noise. Additionally, location of the turbine engines within the lifting air flow ducting, permits suppression of sound from turbine and turbine compressor.

The turbine engine exhausts of both vehicles are exited into the lifting air flow to permit rapid dissipation of exhaust gasses and, thus, minimize the signature to infrared seeking devices.

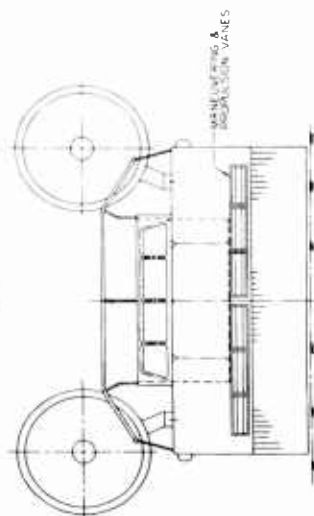
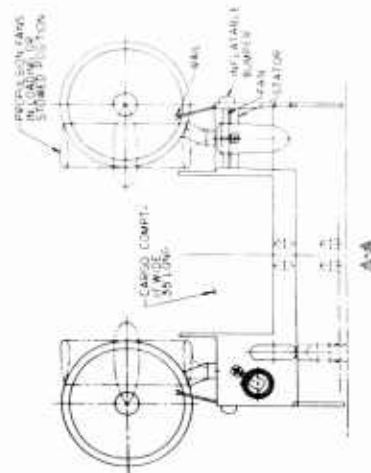
Attention is again brought to the fact that the presented design sketches merely serve to indicate that the analytically determined vehicles can, in fact, accommodate the components and features vital to their operational use. Small (5 to 10 percent) changes to vehicle size can be accomplished to obtain more efficient operational characteristics with only minor alterations to vehicle costs. Additionally, it is anticipated that a refined design analysis, based on more precise structural and flexible skirt characteristic data, would indicate that the minimum lighterage cost air cushion vehicle for LOTS operations is an amalgamation of the vehicles presented.



DESIGN SKETCH 'A'  
PARTIALLY SKEETCHED AIR-WALL VEHICLE  
10 TON PAYLOAD  
W-80 KNOTS



DESIGN SKETCH  
FULLY LOADED  
15 TON PAYLOAD  
40-45 KNOTS



### OPERATING COST PREMISES

To make meaningful economic comparisons of different lighterage vehicles, it is necessary to make compatible assumptions regarding vehicle operational and performance characteristics.

The assumptions listed in the table of Costing Premises reflect as nearly as possible the relative performance capabilities and operational characteristics of each vehicle and provide compatible costing estimates.

The vehicle operating speeds, maintenance rates, and vehicle life are varied with ground environment conditions in an attempt to quantify the effects upon mobility and maintenance which result from operation on less than ideal surfaces.

The costs for the existing amphibians are, for the most part, based upon available cost data and operational planning factors. The helicopter costs are based upon current helicopter experience and extended to include improvements expected in the 1965-1970 period. The ACV costs reflect estimates and assumptions employed in their analysis.

# LIGHTERAGE COSTING PREMISES

	LARC-5 LARC-15 BARC	AIR CUSHION VEHICLE	HELICOPTER
Operational Life, Hours			
Water	20,000	10,000	10,000
Hard Road	10,000	10,000	10,000
Pioneer Road	6,667	10,000	10,000
Cross-Country	3,333	10,000	10,000
Maintenance Rate, Percent of Initial Cost Per Hour			
Water	.01	.01	.017
Hard Road	.01	.01	.017
Pioneer Road	.02	.01	.017
Cross-Country	.03	.01	.017
Speed, Knots			
Water	6-7	40-80	100*
Hard Road	9-17	40-80	100*
Pioneer Road	6-8	35	100*
Cross-Country	3-4	15	100*
Attrition Rate, Percent of Initial Cost Per Year			
	5	5	15
Utilization Per Year, Hours	4,750	4,750	1,500

\*Equivalent speed--cargo carried in external sling inbound  
from ship, no cargo outbound.

### DIRECT OPERATING COSTS

The operating economies of the two LOTS air cushion vehicles selected are compared with those of the wheeled amphibian family of lighters and a helicopter. The assumed LOTS operation conditions for the comparisons shown on the figure include:

- (1) Operation over state three seas (3.5 significant waves)
- (2) Inland distance of 5 nautical miles cross-country
- (3) Ship's hatch rate of 15 tons per hour and unloading rate of 20 tons per hour, and a delay time of 16 minutes per cycle for wheeled amphibians and the ACV. The helicopter has a 4 minute cargo pick-up and 4 minute cargo release time per cycle.

The ACVs are competitive on an operating economy basis with the amphibious family of lighters and are substantially more economical than the helicopter.

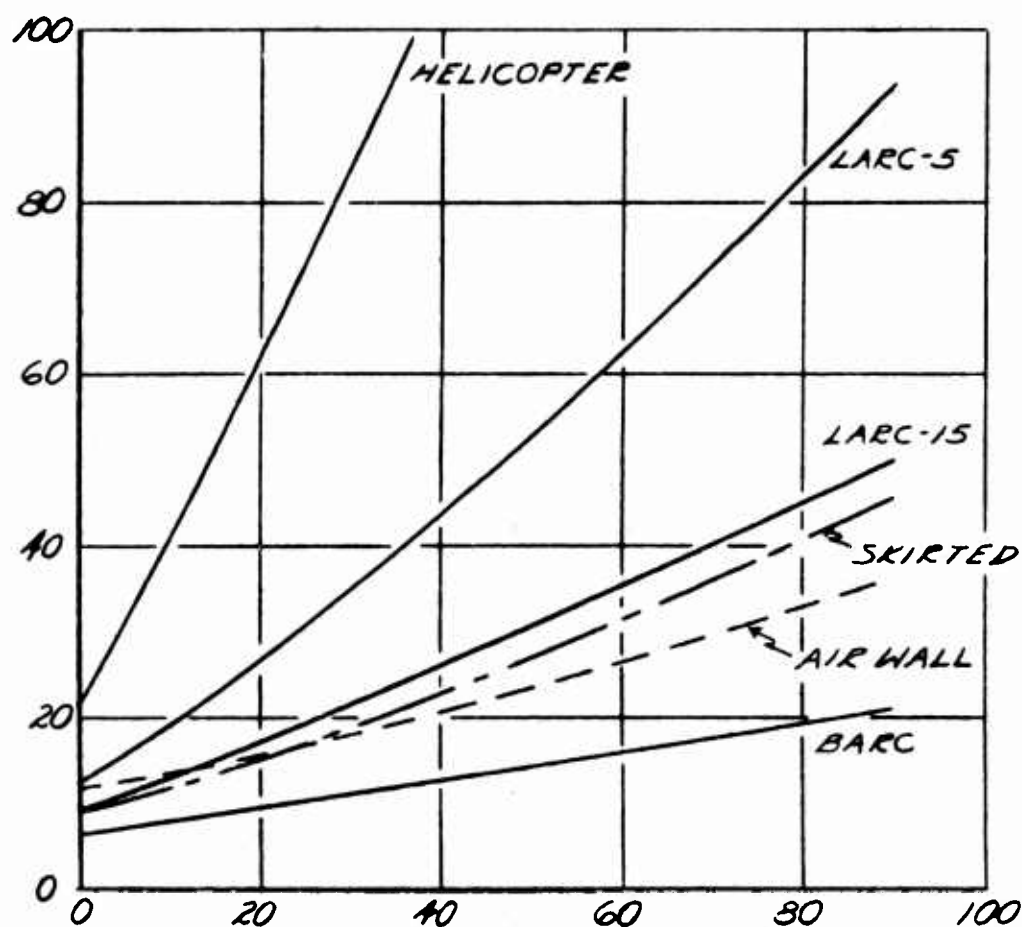
The ACVs, when operated with a 50 percent increase in payload, which still permits operating heights of 2.2 feet, are more economical than the wheeled amphibious family of lighters. Presumably, under ideal conditions, the wheeled amphibians could be similarly overloaded; examination of their cargo compartments shows, however, that there is not sufficient space for even their nominal payloads when typical military cargo is considered. Since the ACVs shown are not cargo space limited, as are the amphibians, they are able to carry a heavier average cargo load. Thus, in a typical operation the ACVs should prove to be even more economical on a system basis than indicated here.

LIGHTERAGE DIRECT OPERATING COST  
INLAND DISTANCE = 5 N. MI., CROSS COUNTRY

HATCH RATE = 15 S. TONS/HR.  
 UNLOADING RATE = 20 S. TONS/HR.

———— SKIRTED VEHICLE - 3 FT. GROUND CLEARANCE  
 - - - - AIR WALL VEHICLE - 3 FT. GROUND CLEARANCE  
 WITH 1 FT. FLEX. SKIRTS

LIGHTERAGE DIRECT OPERATING COST  
 ~ DOLLARS/TON DELIVERED ~



OFFSHORE DISTANCE ~ NAUTICAL MILES

### PROCUREMENT COSTS

It is worthwhile to consider the impact on the budget of the introduction of a new piece of equipment into the inventory. The procurement costs for providing sufficient lighterage in the operating area to obtain a given productivity are shown on the figure of Lighterage Procurement Costs. The procurement costs are shown in relation to the LOTS mission distances.

For the short ship-to-shore distances of current LOTS operations the initial expenditures for air cushion vehicle lighterage would probably be somewhat higher than for the wheeled amphibians. However, the direct operating cost presented previously, which includes the procurement cost amortized over the expected life of the vehicle, is comparable to that of the amphibians. Where longer ship-to-shore distances are contemplated the initial cost of the air cushion vehicles approximates that required for the wheeled amphibians.

Since the given level of productivity considered here is to be maintained on a continuous basis, the procurement cost must include the vehicle availability factor.

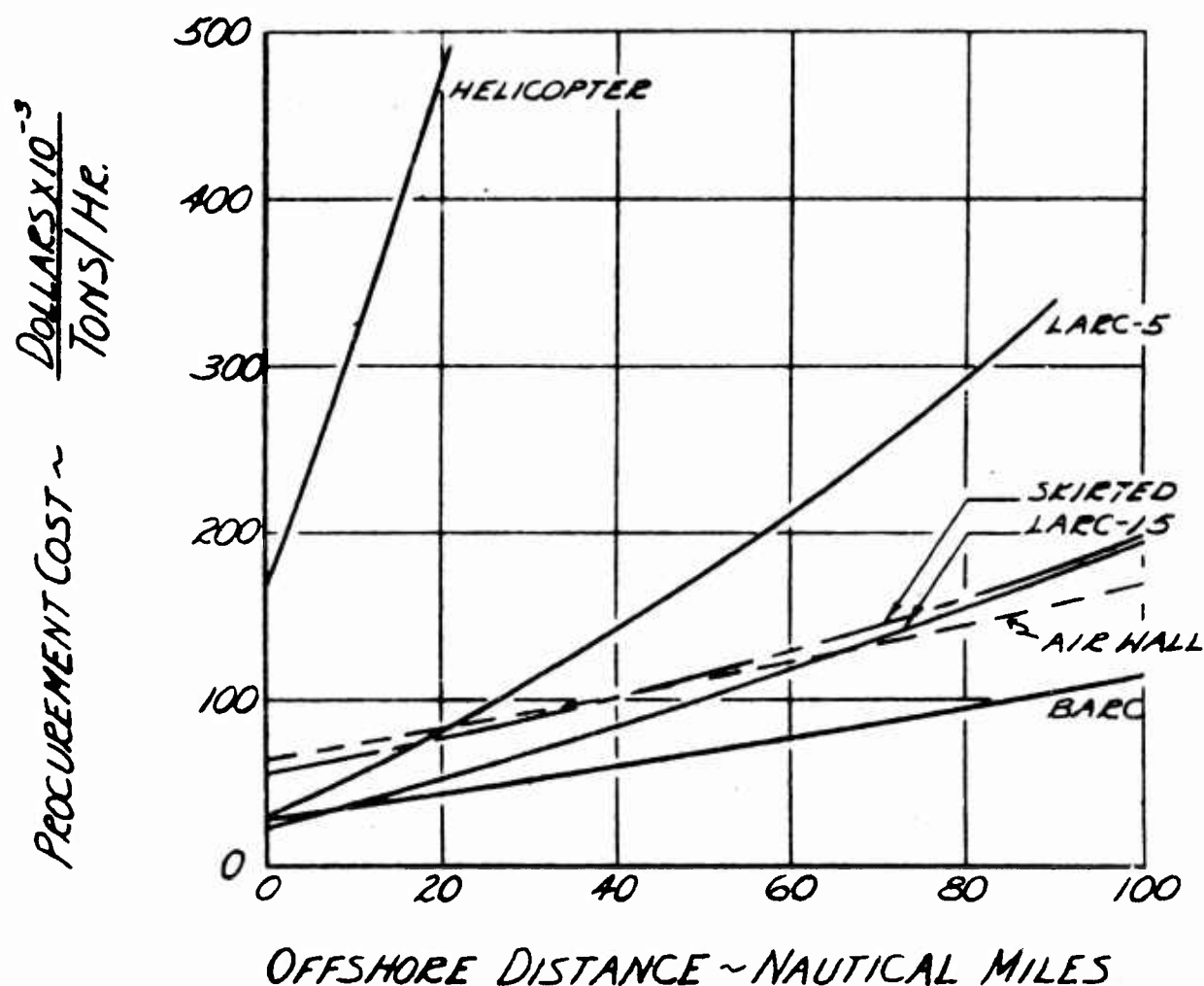
Average availability throughout the 20 hour working day of the LOTS operation is established as 30 percent for the helicopter and 80 percent for all other lighters. The availability of the ACV lighterage is assumed the same as that for wheeled amphibians because of their similarity in mechanical complexity.



LIGHTERAGE PROCUREMENT COST  
INLAND DISTANCE - 5 N.Mi., CROSS COUNTRY

HATCH RATE - 15 S. TONS/H.R.  
 UNLOADING RATE - 20 S. TONS/H.R.

----- SKIRTED VEHICLE - 3 FT. GROUND CLEARANCE  
 - - - - - AIR WALL VEHICLE - 3 FT. GROUND CLEARANCE  
 WITH 1 FT. FLEX. SKIRTS



### INVENTORY AND MANPOWER

The number of lighters required to service a single hatch on a continuous basis is shown in the Figure of Number of Lighters Required. The data include availability factors and thus reflect a comparison of the number of vehicles required in the operation.

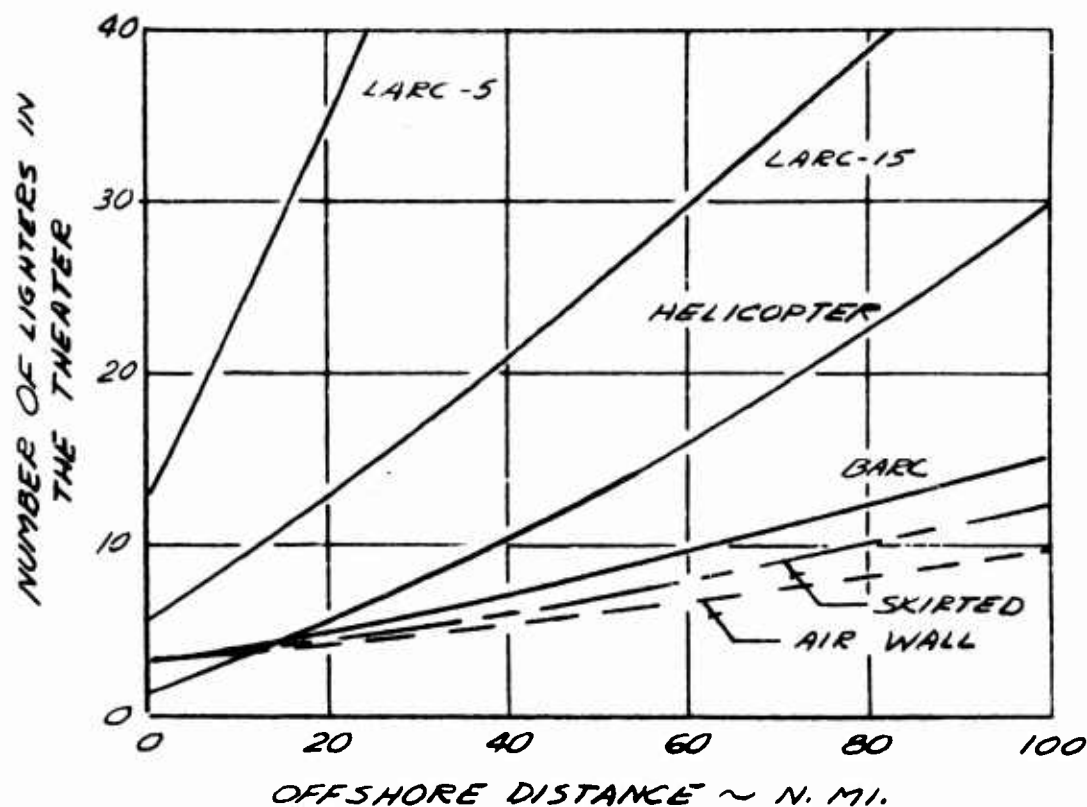
The low availability of the helicopter in comparison to the other lighters causes a significant degradation of its comparative merits.

The ACVs offer a substantial advantage over all existing amphibious lighters in number required in the theater of operations. This advantage also reflects itself in the manpower required as shown in the Figure of Lighterage Manpower Required. This Figure shows the TO & E man hours required for operation and maintenance of the vehicles based upon tonnage delivered. The ACV lighters are shown to require less manpower than any other lighterage type at most operational distances.

NUMBER OF LIGHTERS REQUIRED IN  
THEATER TO SERVICE ONE HATCH  
INLAND DISTANCE = 5 N.MI. CROSS COUNTRY

HATCH RATE = 15 S. TONS/HR.  
UNLOADING RATE = 20 S. TONS/HR.

—— SKIRTED VEHICLE - 3 FT. GROUND CLEARANCE  
----- AIR WALL VEHICLE - 3 FT. GROUND CLEARANCE  
                    WITH 1 FT. FLEX. SKIRT

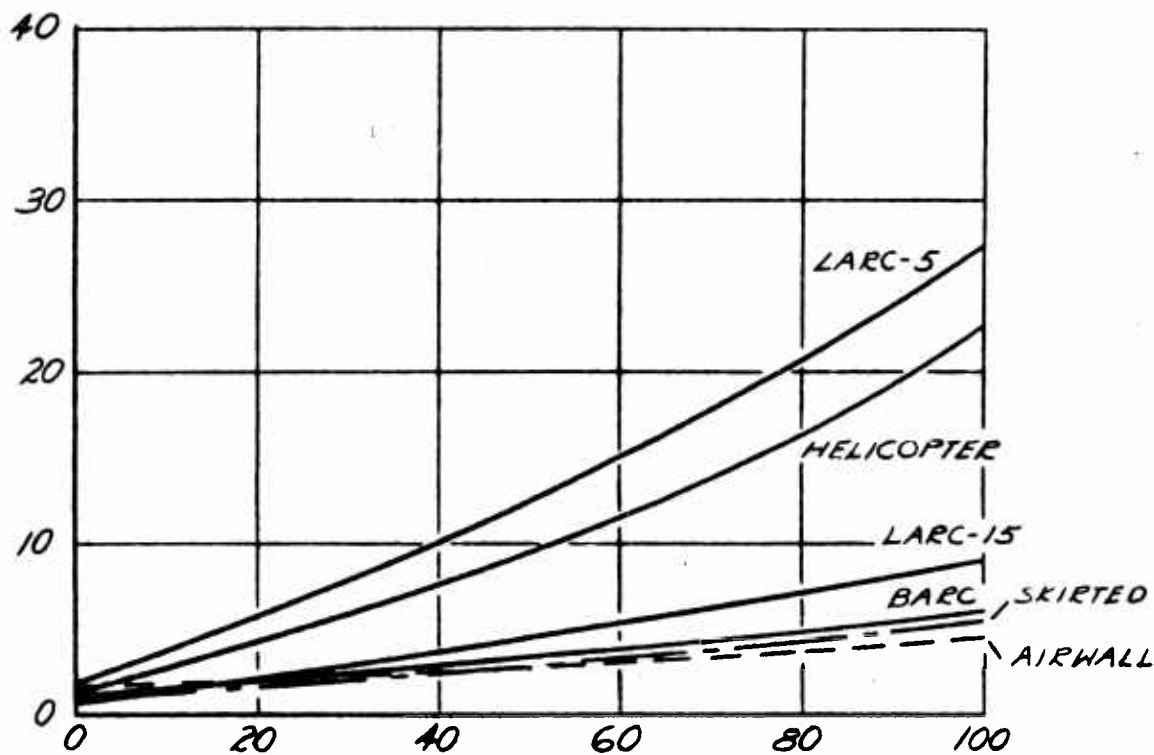


LIGHTERAGE MANPOWER REQUIREMENTS  
INLAND DISTANCE - 5 N. MI., CROSS COUNTRY

HATCH RATE - 15 S. TONS/HR.  
 UNLOADING RATE - 20 S. TONS/HR.

—— SKIRTED VEHICLE - 3 FT. GROUND CLEARANCE  
 - - - AIRWALL VEHICLE - 3 FT. GROUND CLEARANCE  
 WITH 1 FT. FLEX. SKIRTS

T.O. & E. PERSONNEL  
 ~ MANHOURS/TON DELIVERED ~



OFFSHORE DISTANCE ~ NAUTICAL MILES

## TOTAL SYSTEM COSTS

All of the costs of performing the LOTS mission which were considered to be of consequence and could reasonably be quantified were included in the comparison of total system costs. Some costs, such as road construction and transshipment, must be amortized over the operational time span. The figure showing data for Lighterage System Costs presents a comparison of the summed cost factors for the vehicles considered in a representative LOTS mission. The operational time span of the mission varies from 100 to 300 days. In all cases the initial lighter cost is amortized over the vehicles' operational life.

The individual cost factors included are as follows:

1. SHIP PORT COST

- a. Ship depreciation during loading and unloading
- b. Ship crew cost during loading and unloading
- c. Ship fuel cost during loading and unloading

2. LIGHTER DIRECT OPERATING COSTS

- a. Amortization of initial cost
- b. Maintenance costs
- c. Attrition cost
- d. Crew costs
- f. Fuel costs

3. TRANSHIPMENT COSTS

- a. Overseas transport on commercial or MSTs type ships

4. ROAD CONSTRUCTION COSTS

- a. Construction manpower costs
- b. Material costs
- c. Maintenance costs

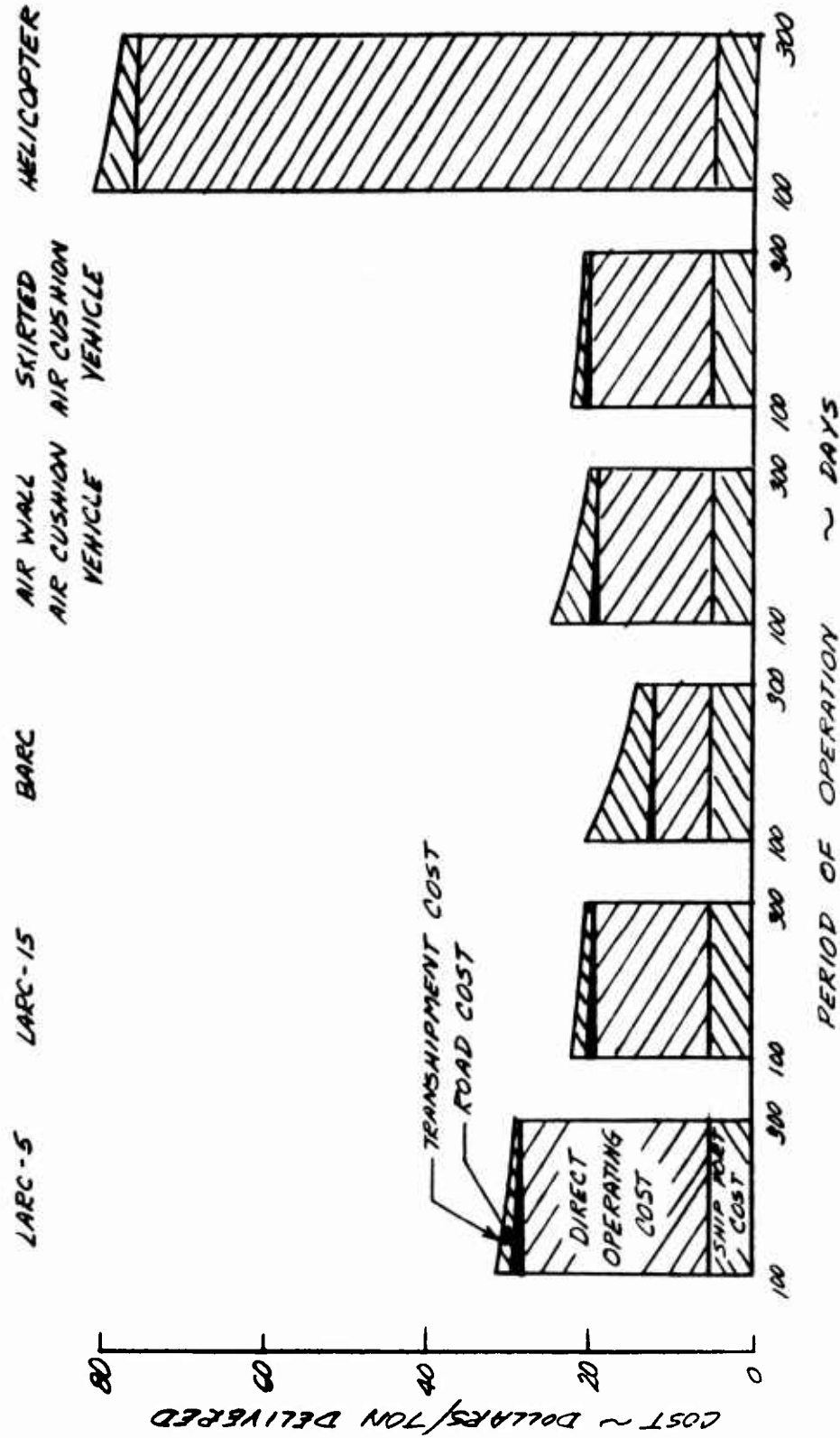
The figure compares the above costs on the basis of tons delivered across the shore for a mission defined as follows:

- a. Ship located 25 nautical miles off shore
- b. Inland supply point located 5 nautical miles inland
- c. Route from shoreline to inland supply point is for wheeled amphibians, a two-way Pioneer combat road, and for ACVs a suitable clearway.
- d. Deck loading of each vehicle for transshipment on MSTs type shipping to an operation 2,200 nautical miles away
- e. Ship hatch rate of 15 tons per hour and lighter unloading rate of 20 tons per hour; except for the helicopter, where cargo pick-up or release times are 4 minutes each.

The total system costs of the air cushion vehicles and the wheeled amphibians are approximately the same. The air cushion vehicles are economically competitive with the wheeled amphibians and provide a significant increase in mobility and mission flexibility. The helicopter is more expensive by a factor of three in the lighterage mission. It offers what may be called the ultimate in mobility, but is limited to off loading specially equipped ships and is restricted to small payloads.

## LIGHTERAGE SYSTEM COSTS

INLAND DISTANCE = 5 N.M.I., PIONEER ROAD  
 OFFSHORE DISTANCE = 25 N.M.I., HATCH  
 RATE = 15 S. TONS / HR., UNLOADING  
 RATE = 20 S. TONS / HR.



### EFFECT OF HATCH RATE

The economy which can be realized by improvements in hatch rates is shown on the figure of Effect of Hatch Rate. The ship port cost and the lighter direct operating costs are combined to reflect costs affected by the hatch rate. The lighterage cost diminishes with increasing hatch rate because of the shorter time spent at shipside.

The variation of ship port plus lighterage cost with hatch rate is independent of mission radius; thus, the variations shown in the figure are applicable to any mission radius with an incremental adjustment to the level shown.

It can be seen from this analysis that increasing hatch rate from 7.2 tons per hour to 15 tons per hour can result in a significant cost savings for all types of lighters.

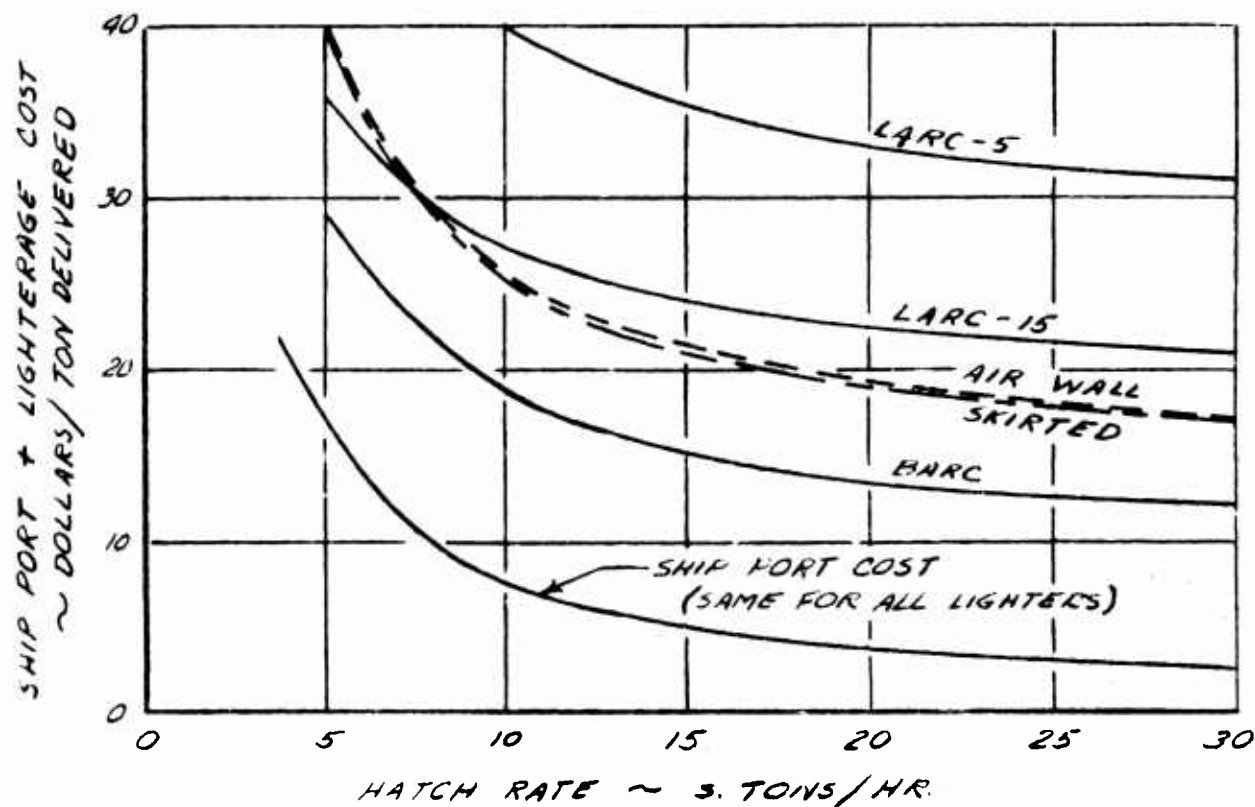
It is possible that such factors as available shipping are more important than the cost variations shown here and may further increase the desirability of increasing hatch rates. As the hatch rate increases, the required number of ships and lighters decreases because of decreased idle times for each. Increasing the hatch rate from 7.2 to 15 tons per hour halves the ship unloading time and reduces the number of ships in the resupply cycle accordingly.



# EFFECT OF HATCH RATE ON SHIP PORT + LIGHTERAGE DIRECT OPERATING COST

OFFSHORE DISTANCE = 25 N.MI.  
INLAND DISTANCE = 5 N.MI. CROSS COUNTRY

———— SKIRTED VEHICLE, 3 FT.  
GROUND CLEARANCE  
----- AIR WALL VEHICLE, 9 FT.  
GROUND CLEARANCE WITH  
1 FT. FLEXIBLE FLAPS



### TRANSHIPMENT ON MSTS SHIPS

Transshipment of the required quantity of lighters to the theater of operations has always posed a sizeable problem. Many methods are used dependent upon the type of lighter, the timing of the operation, the types of ocean vessels available to the operation, etc. When an overseas staging base exists in the vicinity of the intended operation and strategic surprise is not essential, predeployment of lighterage to the staging base and subsequent deployment to the area of operation can be accomplished during the operation build-up stage. When rapid reaction in isolated areas is required, deployment of the lighterage concurrent with the assault and supply shipping is most desirable. The ability to self-deploy or tranship with each supply vessel sufficient lighterage to off-load that vessel at its maximum average hatch rate is a desirable objective.

The specially modified assault ships (APAs and AKAs) have provisions for deck transporting the assault and landing craft required for the amphibious operation. These ships along with LSTs, LSDs and LPDs are limited in number and must necessarily be kept in readiness for assault operations. The resupply of forces overseas must normally be handled by the standard type cargo ships in the MSTS and commercial fleets.

A comparison of the ability to tranship existing wheeled amphibians, and the derived LOTS air cushion vehicles atop ships' hatches is shown on the figure of Transshipment on MSTS Shipping. The figure shows the number of MSTS type cargo vessels required to tranship on deck a sufficient quantity of lighters to serve one cargo ship at an average hatch rate of 15 tons per hour. The effect of ship-to-shore distance is shown for a fixed inland distance of 5 nautical miles. Ships employed in transshipment during the 1965-1970 period are assumed to have boom capacity at all hatches enabling them to load and off-load lighters of less than 10 tons empty weight.

One five hatch cargo ship off-loading at 15 tons per hatch per hour for a 20 hour day can supply the 1,440 tons per day of resupply dry cargo required by a Division Slice. Thus the number of ships required to tranship a sufficient quantity of lighters to supply a Division Slice is as shown in the figure. For current hatch rates of 7.2 tons per hour the quantity of lighters required and therefore the number of cargo ships required for transshipment of the lighterage is only slightly higher, even though two ships must be worked simultaneously in order to supply the 1,440 tons per day.

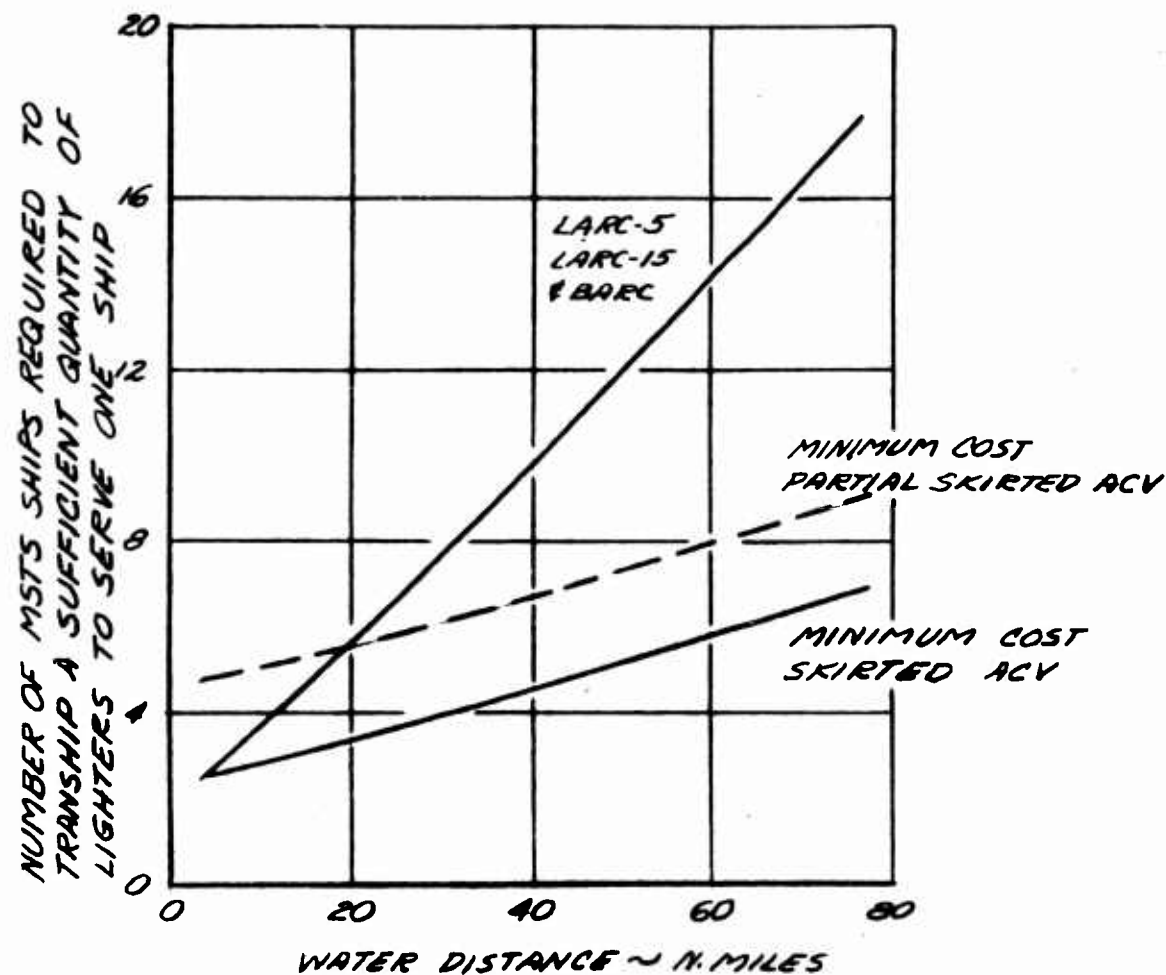
As shown by the figure the transshipment of air cushion vehicles for use in the short ship-to-shore operations of the current LOTS concept does not pose any greater transshipment problem than does the transshipment of present day amphibians.

The short ship-to-shore distances of current LOTS operational planning is mainly the result of performance limitations of current waterborne lighterage. The missile and nuclear threat will probably force the operation to station ships further out to sea or disperse them to greater distances along the shoreline. The numbers of air cushion vehicles required to service the ship are less sensitive to increasing operational distance than the slower amphibians. A greater productive capacity of ACVs can, therefore, be transhipped on a given ship for use in LOTS operations requiring greater mission distances.

# TRANSHIPMENT ON MSTs SHIPPING

## FUTURE SITUATION

HATCH RATE = 15 S. TONS/HR., MIN. BOOM CAPACITY = 10 L. TONS.  
LAND DISTANCE = 5 N.MI., DECK LOADING OF LIGHTERAGE ONLY



### SELF DEPLOYMENT

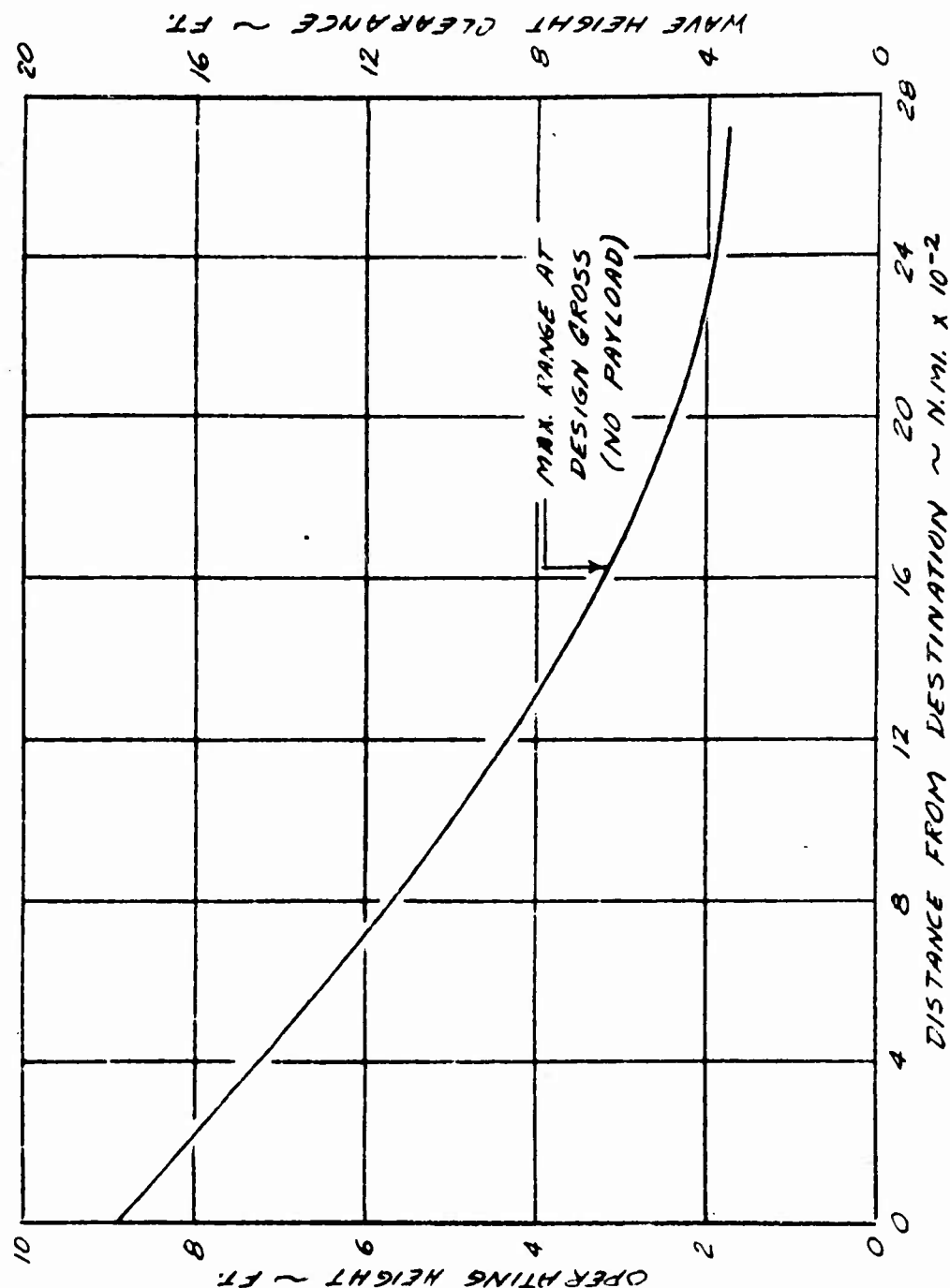
Difficulties encountered in transshipment of sufficient lighterage aboard hatches of MSTs and commercial shipping leads to suggested use of lighter self deployment as a means for circumventing the shortage of available deck space.

A minimum cost partially skirted air cushion vehicle provided with ferry tankage could travel 1,600 n. miles at an operational height of 3.0 feet (6.0 foot wave clearance). As the vehicle proceeds toward its destination, consuming fuel, it would have an increasing capability of rising to operating heights in excess of the 3.0 foot cruising height as shown in the figure of vehicle maximum operating. If the air cushion vehicle was required by sea conditions to operate for significant periods at these higher operating heights, its range would be reduced. However, it would still have a range of approximately 1,000 n. miles even if required to operate at its highest operating heights throughout the trip.

Self deployment of air cushion vehicles designed for LOTS operations is a reasonable consideration. The available vehicle operating heights provide ability to clear unexpected high sea conditions. With its over-water speeds of 80 knots a 1,000 nautical mile trip would take approximately 12 hours. Such trip durations are reasonable in view of crew fatigue, crew provisioning, and reliable weather and sea condition forecast considerations. Practicalities of lighter self deployment should be determined with the first generation LOTS vehicle.

# AIR WALL AIR CUSHION VEHICLE MAXIMUM OPERATING HEIGHT IN SELF DEPLOYMENT OPERATIONS

VEHICLE DESIGNED FOR 3 FT. OPERATION WITH 1 FT. FLEX.  
 SKIRT, 10 TON PAYLOAD AT 125 N.MI. RANGE, CONSTANT  
 SPEED CRUISE AT 80 KN.



## OVERLAND OPERATING ECONOMY

The figure of Overland Transport Costs presents the total transportation costs per ton nautical mile (direct operating costs plus road costs). Vehicle direct operating cost for two miles were used to compute the cost of delivering one ton a mile distance and return empty. The costs also include the cost of route construction and maintenance. Costs of the 2-1/2 ton truck are included to provide a generally known and recognized comparison.

Each "Division Slice" is normally provided with one main road forward. This road must carry the divisions daily resupply tonnage of 1,440 tons of dry cargo. Therefore the amortization of the road construction and maintenance was based on this cargo rate.

The operational time spans at which various route construction becomes economically advantageous, and the relative operational economy of the various vehicles are shown by the figure.

If operations are to extend over a period of less than six weeks, the fully skirted ACV operated cross-country over "scouted routes" offers the most economical operation, a factor of two better than a 2-1/2 ton truck operated off roads. A "scouted route" is a route that has been previously traveled by a survey party and has been so marked to provide the vehicle operators with direction, safe speed and obstacle avoidance information. The BARC appears economical in the cross-country operation; however, such use of this vehicle is highly questionable due to its unarticulated suspension system, and size.

The wheeled vehicle roads are two lane pioneer combat dirt roads or hard surfaced roads as defined in FM 101-10. The ACV clearways are two way routes where obstructions and unevenness which would impede operation below approximately one foot height have been removed. The air cushion vehicle is

costed for 3 foot operating height over such routes so as to allow for a high practical operating speed. The 3 foot operating height over a route cleared to 1 foot obstructions allows a substantial margin for vehicle dynamics and operator judgment. Additionally, the clearways are assumed twice the vehicle width to allow more than ample room for vehicle drift and control response.

The ACV clearway does not require small obstacle removal, fine grading and earth compacting necessary for wheeled vehicles. In fact, many terrain areas would require absolutely no preparation for ACVs, such as, prairie, flat grasslands, marshes, flat cultivated fields, waterways, etc. Hence, ACV clearway costs are computed on the same basis as the pioneer roadways for wheeled vehicles - roadway width equal to vehicle width plus six feet.

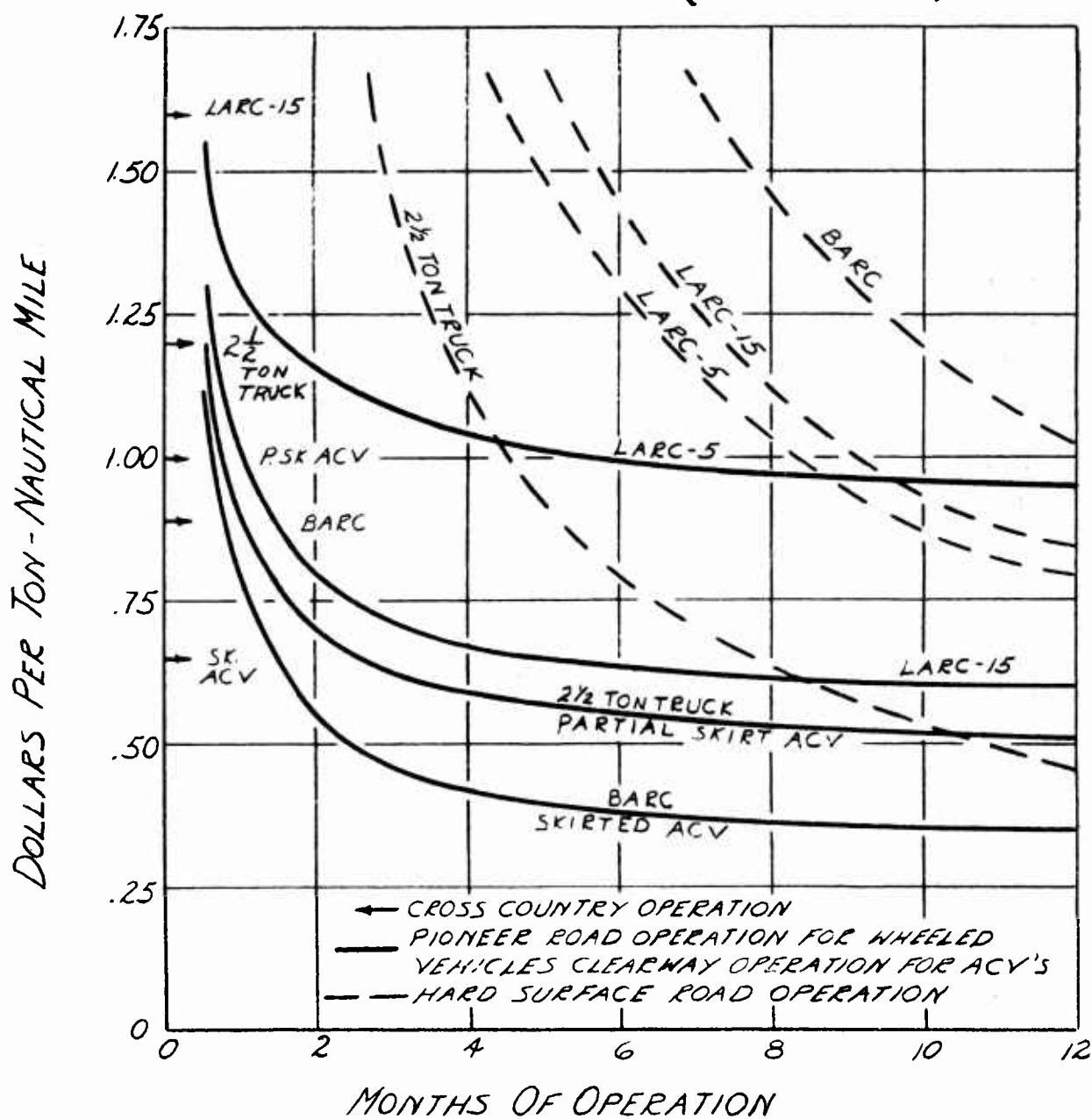
From the data, it is concluded that when operations are expected to extend for periods greater than six weeks but less than a year, the ACVs operated over clearways offer greater operational economy than the other vehicles. The 2-1/2 ton truck operated over hard surfaced roads provides the most economy if the road can be utilized for periods exceeding one year.



# COSTS TO TRANSPORT ONE SHORT TON OF CARGO 1 N. MILE OVER LAND AND RETURN EMPTY

1440 S. TONS TRANSPORTED EACH DAY  
INCLUDES ROAD CONSTRUCTION AND MAINTENANCE  
ACV'S OPERATED AT 3 FEET

{ LARC-5 \$2.67  
PER MILE FOR  
CROSS-COUNTRY  
OPERATION }



## RESPONSE TIME AND COST

The objective of LOTS operations in a military supply system is to provide a steady flow of supplies and equipment to the combat elements. When the resupply operation and the combat situation are progressing as anticipated, the cycle time of an individual lighter only influences the total system economy. Combat situations which develop as anticipated, are indeed the exception. A combat resupply system is continuously being called upon to deliver a priority shipment where vehicle travel time is all important.

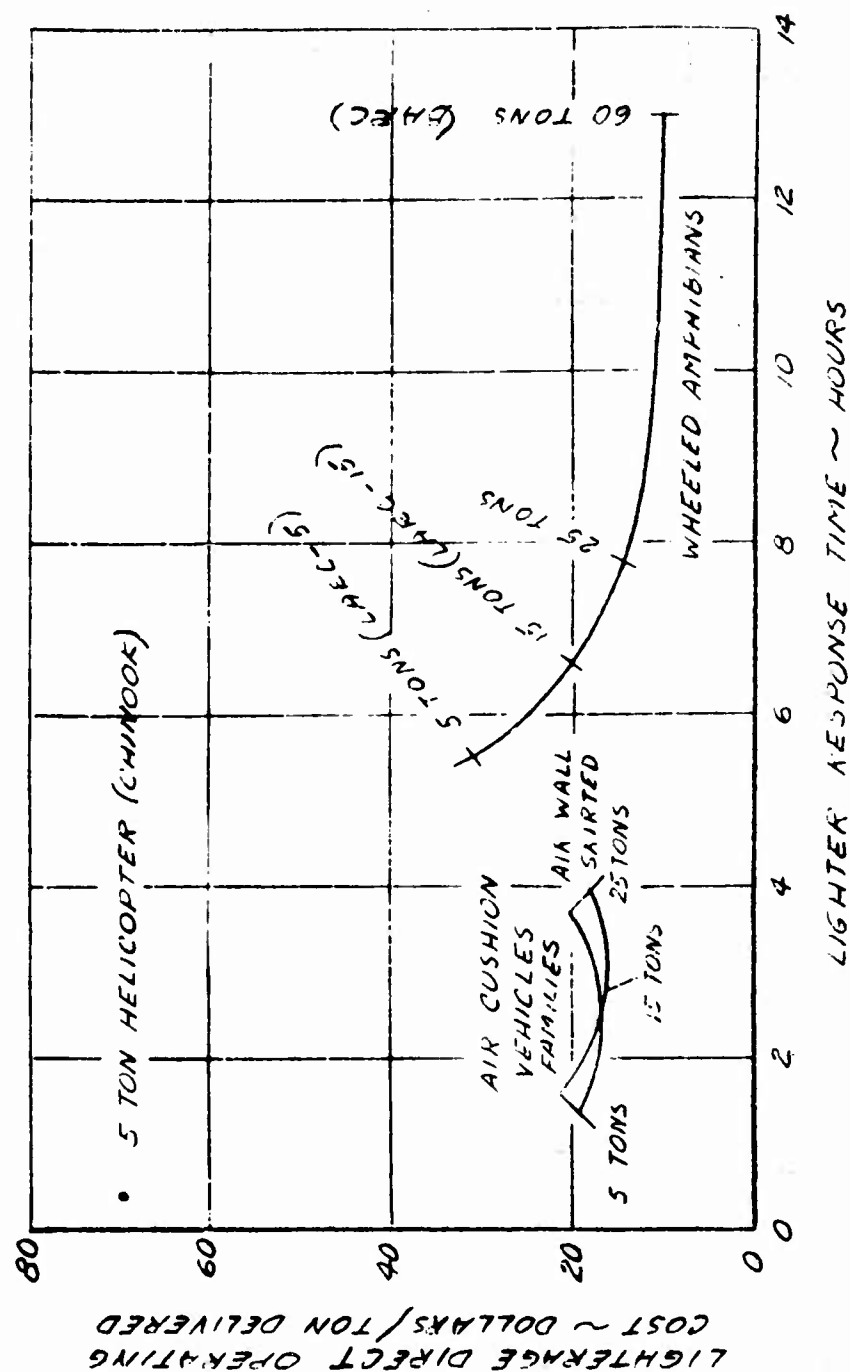
The accompanying figure represents a comparison of the response times and mission costs of helicopters, wheeled amphibians, and air cushion vehicles. The vehicle loading times are those previously stated. The air cushion vehicle operating height is 3.0 feet. The mission distance selected for comparison is 25 nautical miles overwater and 5 nautical miles overland. The response times shown are from start of loading to end of unloading. The data are presented for several vehicle payloads.

For vehicles designed to payload capacities of 20 tons or less the air cushion vehicles can deliver their cargo in less time and at less cost than the wheeled amphibians. For vehicles designed to payload capacities in excess of 20 tons the air cushion vehicles can deliver their payloads in approximately one-half the time. A 5 ton payload air cushion vehicle can deliver its payload in approximately 1.5 hours at an estimated cost of \$20 per ton. A 5 ton payload wheeled amphibian delivers its payload in 5.5 hours at an estimated cost of \$30 per ton.

The helicopter exhibits the shortest response time of all three type vehicles, due to its short cargo pickup times and higher speeds. However, the response time of the helicopter is obtained at a substantial cost premium and it is restricted to working specially equipped ships. The 5 ton payload air cushion vehicles can deliver their cargo within 1.0 hour of the helicopter for less than one-third of the cost.

## RELATIONSHIP OF LIGHTERAGE RESPONSE TIME AND DIRECT COSTS

HATCH RATE = 15 TONS/HR., UNLOADING RATE = 20 TONS/HR.,  
 DELAY TIME = .135, OFFSHORE DISTANCE = 25 N. MI.,  
 INLAND DISTANCE = 5 N. MI. CROSS-COUNTRY  
 RESPONSE TIME = TIME FROM START OF LOADING TO  
 END OF UNLOADING, INCLUDING DELAY



### CONCLUSIONS

On the basis of this study, general engineering knowledge and the limited industry-wide experience in design and experiments with ACVs, the following conclusions have been reached regarding the use of ACV lighters in LOTS operations.

1. The ACV lighter can be made economically competitive with the present inventory of wheeled amphibious lighters. The ACV lighter has potential of reducing the total lighterage inventory and manpower associated with lighter operations.
2. The ACV lighter offers the capability to economically extend the possible shoreline and inland terrain environments and the mission distances over which LOTS operations can be conducted.
3. The ACV lighter provides the flexibility and the immediate response required to meet the exigencies of a dispersed and rapidly moving military situation.
4. The ACV lighter is operationally compatible with existing lighterage equipments which it may progressively replace and with current and projected complementary and supporting equipments.
5. The ACV lighter can be introduced into the Army inventory without untoward impact upon organizational structure or applicable standing operational procedures.

6. The transshipment of equivalent productive capacities of ACV lighterage poses no greater problem than does the transshipment of wheeled amphibians. Should lighter operating distances increase, a greater productive capacity in ACV lighterage could be transhipped in an average MSTS ship.
7. Self deployment of ACVs appears economically and operationally possible due to their high speed and ability to clear increasingly higher waves as the mission progresses.
8. Two configurations of ACV lighterage presenting superior but significantly dissimilar technical characteristics are recommended by the results of the study. The dissimilarities are the result of the degree of skirting employed, and serve to emphasize the need for additional detailed skirt and vehicle design refinement.

### RECOMMENDATIONS

In view of the potential increases in military capabilities obtainable at reasonable cost in the 10 ton capacity partially skirted air wall configuration and in the 15 ton capacity fully skirted configuration of ACV lighterage, it is recommended that:

1. Comprehensive preliminary design and analysis of both types of air cushion vehicles suggested by this analysis should be carried forward simultaneously until such time that the studies indicate one vehicle type to be clearly superior. Construction of the selected vehicle to serve as an experimental first generation operational vehicle should be accomplished. Intensive and comprehensive operational tests of the vehicle in realistic operational LOTS missions should then be accomplished to provide the data necessary for future design and formulation of sound military policy toward use of air cushion vehicles in LOTS operations.
2. Because of the economic sensitivity of ACV lighterage to structural weight, it is recommended that sufficient experimental tests and analytic studies be conducted to determine with reasonable exactness the structural loads that will be imposed by wave impact in both cushion borne and water borne rough water operations. Use of the above recommended vehicle for performance of the tests is considered desirable.

3. The potential benefits from use of flexible skirts on ACV lighterage makes obligatory the recommendation that substantial effort be devoted to experimental test and analysis of skirt element structural design and drag.
4. Further analysis of operations to include consideration of an ACV lighter family and a mix of ACV and other lighters to provide total system capability at minimum cost is recommended. Such analyses should include the operational data obtained with the ACV and other lighter types such as amphibious hydrofoil and amphibious planing; hull craft which are currently under research. Additionally, such analysis should include consideration of the effects of partial loss of the lighter force.

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